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THE LOESS SOILS OF THE NEBRASKA PORTION OF THE TRANSITION REGION:

I. HYGROSCOPICITY, NITROGEN AND ORGANIC CARBON.[1]

By

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INTRODUCTION.

"The sloping plains country lying between the Rocky Mountains and the Mississippi, quite arid at the foot of the mountains, but with rainfall increasing more or less regularly to eastward, forms a transition-belt between the arid and the humid region of which but a small portion[3] has been systematically studied with respect to its soil formation" (18—*Hilgard,* Soils, p. 397).

In this *transition region* no other surface formation seems to offer such an opportunity for the study of the relation of the properties of its soils to the climate as does the large area indicated in Fig. 1 as derived from wind-laid material and commonly referred to as *loess.* The soils of about half of Nebraska are derived from this deposit and the agricultural importance of these far exceeds that of all the other soil areas combined. The Dune Sands which occupy most of the north-central portion of the state are devoted almost exclusively to pasturage. Residual soils, while extensively developed, are almost entirely confined to the distinctly semi-arid western portion of the state. Glacial soils occupy a considerable portion of the southeastern part of the state, but much of their area is too

[1] Received for publication February 10, 1916.

[2] The work reported in this paper was carried out at the Nebraska Agricultural Experiment Station, where the authors were Chemist and Research Assistant in Chemistry, respectively.

[3] This "small portion" refers to parts of Minnesota and North Dakota.

rough for satisfactory tillage and hence their agricultural importance does not correspond to their acreage. The loess, on the contrary, although in a few places too badly dissected to permit of cultivation, in general forms level plains or comparatively gentle slopes, ideal for tillage, and only a small part of it lies so far to the west as to be very seriously affected by a lack of sufficient rainfall. All of these factors combine to give the loess soils the most prominent place in the study of Nebraska agriculture.

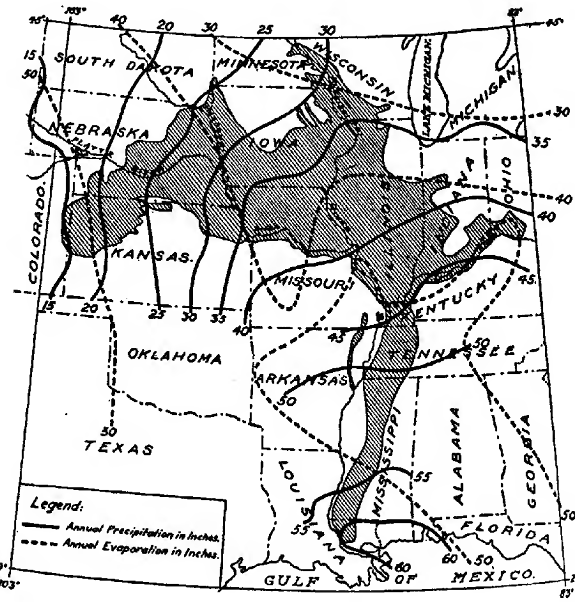

Fig. 1.—Map showing distribution of loess[1] in the United States and also the annual precipitation[2] and evaporation[3] of the loess region. ([1]From map by G. N. Coffey, to accompany Bul. 85, Bur. Soils, U. S. Dept. Agr., 1912, and map of Reconnoissance Survey of Western Nebraska, Bur. Soils, 1913. [2]Climatology of U. S., Plate xxvi, 1906. [3]Monthly Weather Review, 1904, fig. 1, p 558.)

Uniformity in physical properties has long been recognized as characteristic of the loess, but previous to the studies partly reported in the present article little attention had been paid to the chemical composition of the Nebraska portion.

Within only recent years has it come to be recognized, first through the work of Hilgard in the United States, and later through the work of Dokutschajew and Sibertzew in Russia, that in general the character of the soil is much more dependent upon the climate of the region in which it is found than upon the character of the rock from which it has been derived, or upon the manner of its formation. Thus a granite may weather to produce a soil very similar to that developed upon a wind-laid silt loam or a lacustral clay when all three have been exposed for a sufficient length of time to the same climate, while all will be quite distinct in character from the soils that would have resulted under a radically different climate.

According to climate soils are classified as those of ***humid regions***, in which the precipitation exceeds the evaporation, and those of *arid regions*, in which the precipitation is less than the evaporation from a water surface (23, p. 523). It is difficult to define sharply the limits for either class. In addition to the amount of the annual precipitation it is necessary to take into consideration its distribution as well as the temperature, the relative humidity of the air, the wind movement and the intensity of the solar radiation. Accordingly, the usual meteorological data do not give us definite information as to the class to which the soils of a region belong. A much better criterion is the amount of percolation which the soil suffers; if the seepage is considerable it is under humid conditions.

The Committee, of the American Society of Agronomy, on Soil Classification and Mapping has recently proposed to recognize a third division to embrace the soils of the ***semi-arid*** regions (13, p. 285).

The uniformity in physical properties, recognized as characterizing the material of the loess, should tend to produce, under uniform climatic conditions, soils uniform in chemical properties. The importance of working with soils of similar texture in a study of the relation of their chemical composition to climate is evident, as the most marked effect of a heavy precipitation is the leaching out of the soluble salts and the carbonates. A precipitation, too light to cause the water to penetrate beyond the reach of the plant roots in the case of a fine-textured soil, may regularly cause percolation in an adjacent sand, the water-holding capacity of the latter being much lower. There would thus be developed in the former the characteristics of an arid, and in the latter those of a humid soil, although the two types may be adjacent.

The residual soils immediately to the west and northwest, where similar in water capacity, may be expected to resemble those of the adjacent loess. Likewise, the glacial soils of the southeastern part of the state are likely to show many of the characteristics of the loess around Lincoln and Weeping Water.

The mode of deposition of this æolian deposit makes it highly prob-

able that the portion of it now constituting the soil and subsoil was originally very uniform in chemical composition, at least within the limits of different districts, even though it may have shown great variations between distant parts, as when that in Ohio is compared with that in eastern Colorado.

Our study of the loess has been confined entirely to the Nebraska portion, which offers exceptional advantages, the humidity decreasing steadily from the Missouri to its western limit. The formation covers the hills and valleys alike to a depth of from 20 to 100 feet, being much thicker than this in some places and much thinner in others. Throughout the first hundred miles westward from the Missouri it is underlain by Kansan till, while throughout the remainder of the distance it overlies Cretaceous and Tertiary formation (7, p. 169; 14).

The dark-colored prairie soils which occupy the Nebraska portion of the loess have been recognized as similar to the Russian Chernozem (black earth). The chief labors of Russian soil investigators have been devoted to the Chernozem and they emphasize the paucity of data on similar soils in the United States. Thus Kossowitsch (20, p. 338-339) makes the following statements:

> "Concerning the Chernozem soils of North America as such we know very little; the American soils investigators, in so far as we know, actually even do not recognize any special soil type which would be analogous to the Russian Chernozem soils. The zone . . . . . of the Chernozem extends approximately through the states of North and South Dakota, Nebraska, Kansas, Oklahoma and Texas, but at present we do not have any at all definite data to make it clear how wide this zone is, and to what extent the representatives of the Chernozem soils occur in it."
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> "Unfortunately we do not have available chemical analyses of the different levels from typical soils of the prairies mentioned. The data of such analyses would make it possible for us to elucidate more fully the peculiarities of these soils and their real nature."[1]

Even for the Chernozem soils of Europe he finds, on assembling the available data, that only very few such analyses have been published, and even these are far from complete. Nabokich (22, p. 203) points out that there is still lacking a knowledge of the exact character of the vertical profile of most of the soil types of Europe, the chemical study of the successive soil levels begun more than thirty years ago by Dokutschajew, Schmidt, Berendt, Müller and others having been neglected by the soils investigators who followed them.

[1] Author's translation from Kossowitsch, loc. cit.

As no other soils from the regions of summer rains have contributed so much to the study of the relation of soil character to climate as have the Chernozem soils of Russia, both the analytical data and the agricultural history of these are of especial interest in connection with the soils of the transition region. Because of their three most marked characteristics—great fertility, richness in organic matter and wide distribution—they early attracted the especial attention of Russian investigators, and the explanation of their origin has been a matter of controversy for over a hundred years. They occupy the greater part of the southeastern half of European Russia. Toward the north and northwest they pass gradually into the gray, forest-covered soils, there being no sharp line of separation, while on the southeast they assume a chocolate—or chestnut-color and merge into the light-colored soils of the desert areas. Thus with a steady increase in the humidity of the climate the light-colored soils of the southeast pass into those darker in color and these in turn into the typical black soils (Chernozem). With still increasing humidity the latter show a gradual change into the light gray forest soils. The productivity attains a maximum along with the color, the light desert soils being unproductive from lack of rainfall and the light-colored forest soils because of the lack of the essential elements of nutrition.

The climate of the Chernozem zone in Russia resembles that of western Nebraska in that it is cold in winter with a small snow-fall, has hot summers with a dry atmosphere, is subject to sudden changes of temperature, and is characterized by insufficient precipitation. This want of moisture is due less to the amount, 16 to 20 inches, than to its distribution. It falls chiefly during the warm, growing season, and is quickly transpired by the plants or evaporated. Much falls in heavy showers, causing a great loss in the form of run-off. The fineness of texture of the soils increases both the runoff and the evaporation. The natural vegetation is similar to that of our prairies, but Russian investigators report that it is very difficult to now find any really virgin fields.

The Chernozem soils occur chiefly on the loess and there is still found outside of Russia the erroneous view that they are *confined* to this geological formation. Extensive areas occur on the glacial plains, lacustral clays, limestone and crystalline rocks, sufficient evidence that this soil's formation depends upon the climate rather than upon the character of the parent rock. One property possessed in common by all geological formations on which this black soil is typically developed is their ability to produce a fine-textured product on weathering. The topography on which the Chernozem occurs is similar to that of our prairies—almost level to gently rolling.

It is now generally accepted that the grassland vegetation has caused the dark color of the Chernozem soils. The large quantities of roots

left by the plants were not provided with conditions favorable to rapid decay, the soils being throughout most of the year either too dry or too cold. The plants, consisting largely of biennials or perennials rooted deeply, and the roots were of short life compared with those of forest vegetation. Thus large quantities of the dead roots were annually added to the soil. Considerable amounts of the aerial parts of the plants were dragged down by insects or fell into crevices during dry weather. It is not improbable that soluble organic compounds from the aerial parts were carried down into the soil by the rains. In passing from the most arid to the most humid portions of the plains the conditions favored an increased rate of growth but also an increased rate of decay. Up to a certain point the former increased the more rapidly and at that point there is found the maximum accumulation of organic matter.

Kossowitsch (20, p. 333) states that the Chernozem soils, both in physical and chemical respects, possess the very best properties which good arable soils must have, that in so far as the supply of plant nutrients is concerned they are to be classed with the most fertile, and that under cultivation they retain their fertility a very long time, which may amount to some hundreds of years. The actual conditions of climate that have produced these soils cause the years of rich harvests to alternate with those of light yields, during which the draught upon the soil is very light. Signs of exhaustion appear first in those derived from the poorer parent rocks and formed under a more humid climate. In general, the Chernozem soils begin to show first the lack of phosphoric acid and later that of nitrogen.

Methods of Sampling.

In an investigation such as this the method of taking the samples to be used for analysis is extremely important. We had planned to collect samples from each of the eight precipitation-belts shown in Fig. 2. None was secured from the 32 + or the 22 to 24 inch belt. On account of the recent series of dry years, McCook, which at the time of beginnig the work was regarded as in the 20 to 22 inch belt, now has to be placed along with Wauneta, which was selected as representative of the 18 to 20 inch belt.

TABLE I.

LONGITUDE, ELEVATION AND NORMAL PRECIPITATION AT TOWNS NEAR WHICH THE SOIL SAMPLES WERE COLLECTED.

Stations of the U.S. Wthr. Bur.	Approximate longitude	Elevation feet	Normal annual precipitation, inches	Length of record, years
Wauneta	101° 30′	2934	18.55	25
McCook	100° 40′	2506	18.83	[1]30
Holdrege	99° 20′	2324	24.24	20
Hastings	98° 20′	1932	26.87	22
Lincoln	96° 40′	1189	27.51	31
Weeping Water.	96° 10′	1080	30.19	37

[1] See footnote 2 to Table IV.

The soil samples were collected from only virgin prairie fields near one or other of the six stations of the United States Weather Bureau mentioned in Table I, for each of which a precipitation record of twenty years or more is available. The location of these is shown in Fig. 2.

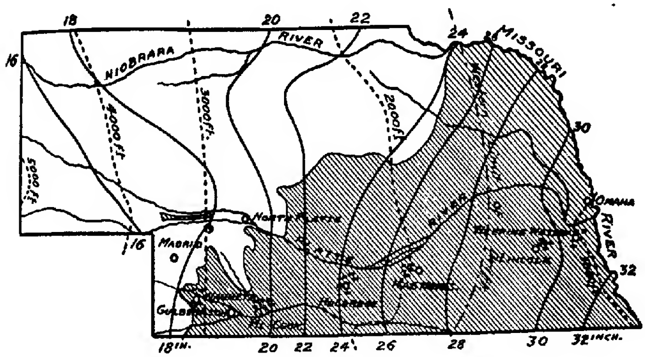

Fig. 2.—Map of Nebraska showing distribution of the loess, precipitation belts, the altitude and the location of fields sampled.

The original intention was to select in each locality five level, virgin fields located to one another as are the four corners and the center of a square whose sides are two miles in length. However, on account of the great scarcity of virgin fields which were at all level, the original plan could not be adhered to closely. Along the different river courses and in the southeastern counties, where the loess overlies the Kansan till, it has been extensively eroded, in the latter in many places remaining as only small isolated plains. Also in many places on the divides in the western portion it has been eroded, and in such cases, while not usually exposing the underlying geological formation, the surface coating with its high content of organic matter, characteristic of the level or rolling prairies, has been largely removed. Thus, while numerous virgin fields were found, only a few of these were representative of the tillable areas of loess soil. The very characteristics which we desired our typical fields to possess had appealed to the farmers and caused them early to bring such land under the plow. All fields in valleys were avoided, as were also those in which the loess was found to have a depth of less than six feet. We were, however, able to select in each of the six localities mentioned in Table I five fields which, since the advent of settlers,[1] have been used as pastures or as meadows, or partly for both purposes. None of these

fields was more than ten miles from the Weather Bureau station whose name is given the area for the purpose of the present discussion. The legal description of each is reported in Table II. All, at least in the parts sampled, were almost level or only slightly rolling. Those of the two eastern areas, Weeping Water and Lincoln, had been used chiefly as meadows, while those of the areas to the west had been used mainly, or altogether, as pastures. The location of the selected fields with respect to the farmsteads, together with the system of farming followed, renders it improbable that there had been any additions of potash or phosphoric acid due to the application of fertilizers of any kind or to feed from elsewhere having been given the pasturing animals while on these fields. The amount of organic matter in the surface soil may be somewhat less in the fields used as meadows than would have been the case if they had been pastured, but it is probably fully as great as though they had been exposed to periodic prairie fires, such as prevailed before the settlement of the state. So, on the whole it seems extremely probable that the soil of the fields, when the samples were taken in 1909 and 1910, was similar in composition to what it was when *truly* virgin—before the advent of settlers. A typical field in each of the areas is shown in Plates I, II and III.

From each field two sets of samples were taken—the one consisting of the *foot-samples* and the other of the *inch-samples*. For the former ten borings, at intervals of 30 feet along a line across the most level portion of the field, were made to a depth of 6 feet, and composite samples prepared of each foot section, thus giving six samples, later referred to as "field-samples," which are not to be confused with the "area-samples," prepared by mixing equal weights of the corresponding five "field-samples." Two soil augers, one of 2.25 and the other of 1.5 inch diameter, were employed. The former was used for taking the samples of the surface foot, as well as for enlarging and cleaning out the hole preparatory to sampling each of the lower foot sections with the smaller auger. Great care was exercised to prevent any of the soil from nearer the surface becoming mixed with the samples from the lower levels. Thus, in addition to using augers of different sizes, carefully enlarging and cleaning the hole with the larger one before taking a section with the smaller, the auger, on being withdrawn with the attached soil, was closely examined for any material which might have come from nearer the surface, and if this was found it was removed with a knife. The aerial portions of living plants were not included with the sample, but roots and plant debris were treated as integral parts of the soil.

[1] Mr. A. E. Sheldon has furnished the following approximate dates at which practically all of the Government land had been taken in the different localities: Weeping Water, 1865; Lincoln, 1870; Hastings, 1885; Holdrege, 1892; McCook, 1900; and Wauneta, 1904. He states also that settlements had been made about 1854 at Weeping Water, 1858 at Lincoln, and between 1869 and 1876 in the more westerly localities.

TABLE II.

LOCATION OF THE FIELDS FROM WHICH THE SOIL SAMPLES WERE TAKEN.

Field No.	Part of Section	Section	Township	Range	From 6th Principal Meridian
		WAUNETA.			
I	W½ of NW¼	4	4	36	West
II	SE¼ of NE¼	23	6	36	West
III	SE¼	10	5	36	West
IV	E½ of NE¼	22	6	37	West
V	NE¼	34	5	36	West
		McCOOK.			
I	SW¼ of SW¼	10	3	29	West
II	NE¼ of NE¼	10	3	29	West
III	N½ of NE¼	8	3	29	West
IV	W½ of SW¼	4	3	29	West
V	N½ of SW¼	8	3	29	West
		HOLDREGE.			
I	N½ of NW¼	33	6	18	West
II	SE¼ of NW¼	7	5	18	West
III	E½ of NE¼	9	5	18	West
IV	N½ of NE¼	33	6	18	West
V	SE¼ of NW¼	34	6	18	West
		HASTINGS.			
I	N½ of NE¼	17	7	10	West
II	SE¼ of NE¼	12	7	11	West
III	SE¼ of SE¼	16	7	10	West
IV	SE¼ of SE¼	4	7	10	West
V	SE¼ of SW¼	6	7	10	West
		LINCOLN.			
I	Near center of SE¼	20	10	7	East
II	S½ of NE¼	29	10	7	East
III	E½ of SW¼	27	10	7	East
IV	E½ of E½	2	10	7	East
V	W½ of NW¼ of SW¼	23	10	7	East
		WEEPING WATER.			
I	SE¼ of NW¼	27	11	11	East
II	SW¼ of NE¼	26	11	11	East
III	NE¼ of SW¼	14	10	11	East
IV	NW¼ of SW¼	33	11	12	East
V	N½ of SE¼	34	11	12	East

It seems highly probable that the six area-samples, each a composite from 50 individual borings, from any one area represent material originally alike, any marked differences between them being due to alterations that the material experienced since its deposition. The inch sections

were taken from the first foot only, being composites of 20 (and in the fields of the Lincoln area of 50) individual samples. They were secured by means of a brass tube 1⅜ inches in diameter provided with a wide collar 6 inches from the end. The tube was forced into the ground until the collar rested firmly on the surface. The core was forced out and then, after first removing the soil to a depth of six inches by means of a spade, the second 6-inch layer was sampled in the same manner. Each of the two cores thus obtained was subdivided into six equal lengths, the first inch section having the living vegetation trimmed off level with the surface of the soil. The area inch-samples, accordingly, are composites of 100, or 250, individual samples.

In all 648 samples were subjected to more or less complete analysis in this investigation, each of the six areas being represented by 108, consisting of 36 foot-samples and 72 inch-samples.

THE CLIMATE.[1]

The altitude of the loess-covered portion of Nebraska rises gradually from east to west; all the Weeping Water fields sampled touch the 1200 foot contour line while all those at Wauneta are from 3100 to 3400 feet above the sea level.

The gradual change in altitude from east to west is not accompanied by a corresponding change in temperature, the uniformity of which, throughout the region studied, is shown by Table III, in which are given the data for four of the stations. There is no record for Wauneta, and only a very incomplete one for Weeping Water, but conditions at these two stations differ little from those at McCook and Lincoln, respectively. The mean annual temperature is 50.1° F. at Lincoln and 51.8° at McCook. February, the coldest month, shows a mean of 24.8° at the former and 27.7° at the latter, and July, the warmest month, of 76.4° and 77.4°, respectively. In most years maximum temperatures of about 100° are recorded a few times during the warm season, July, August and the early part of September, and minimum temperatures of 15° to 20° below zero during the winter months. Occasionally temperatures as high as 110° and as low as 30° below zero occur. The season without killing frosts usually extends from the first of May to the first week in October, but these have been experienced as late as the last week in May and as early as the second week in September.

[1] For the data on climate we have made use of the various publications of the United States Weather Bureau dealing with Nebraska, especially the Summaries of the Climatological Data for the United States for Sections 35, 36 and 37, the Annual Summaries for the Nebraska Section, and the Annual Reports of the Chief of United States Weather Bureau. In addition, unpublished data have been furnished us by Mr. G. A. Loveland, Director of the Nebraska Section of the Bureau.

TABLE III.

TEMPERATURE DATA, IN DEGREES FAHRENHEIT, FOR THE DIFFERENT STATIONS.

MEAN TEMPERATURES.

Station	Length of Record, Yrs.[1]	January	February	March	April	May	June	July	August	September	October	November	December	Annual
McCook	14	27.8	27.7	39.0	51.3	62.6	72.5	77.4	76.5	66.6	53.4	38.7	28.0	51.8
Holdrege	20	26.0	26.7	37.2	50.9	60.9	71.9	76.6	75.2	67.2	52.8	38.5	28.5	51.0
Hastings	22	24.4	24.7	36.9	50.1	60.6	71.5	75.6	74.4	65.3	52.8	38.8	26.8	50.0
Lincoln	31	21.2	24.8	36.0	50.7	62.9	71.6	76.4	74.3	65.2	53.3	38.0	26.9	50.1
HIGHEST RECORDED TEMPERATURES.														
McCook	14	78	74	91	98	101	106	110	107	102	94	85	71	110
Holdrege	20	70	78	92	101	102	106	108	108	115	92	88	65	115
Hastings	22	70	71	90	93	96	103	108	104	101	91	78	66	108
Lincoln	31	66	79	91	97	98	103	110	107	103	92	80	71	110
LOWEST RECORDED TEMPERATURES.														
McCook	14	*30	*38	*5	18	14	44	44	40	22	12	*8	*21	*38
Holdrege	20	*26	*43	*9	10	19	38	42	42	29	7	*8	*12	*43
Hastings	22	*30	*30	*5	18	22	41	48	43	28	9	*5	*13	*30
Lincoln	31	*29	*26	*11	17	25	43	49	43	27	15	*15	*18	*29

[1] Including 1914. * Below zero.

The precipitation (Table IV) decreases from east to west, the mean annual amount being a little more than 30 inches at Weeping Water and a little less than 19 at Wauneta, or an average decrease of about one inch for each 25 miles. Most of it falls during the growing season, and only less than one-tenth of it during the three winter months. June is the month of maximum precipitation and January of minimum. About half of the rainfall of May, June and July is from rains of one inch or more in 24 hours. In most years some part of the region has a storm with a rainfall exceeding 2 inches in 24 hours and occasionally this rises to 5 or even 8 inches. The fall of such a large part of the total precipitation in the form of these storms of brief duration accounts largely for the observed deficiencies of moisture for crops in seasons when the recorded rainfall would indicate an abundant supply, much of the water running off the surface before there is time for it to be absorbed by the soil. The number of days with a precipitation of 0.01 inch or more decreases from east to west more rapidly than does the total precipitation, averaging over 80 at Weeping Water and Lincoln and less than 50 at Holdrege and McCook. For those days on which the precipitation amounts to 0.01 inch or more it averages 0.34 inch at Weeping Water, 0.32 at Lincoln, 0.40 at Hastings, 0.52 at Holdrege, 0.43 at McCook, and 0.36 at Wauneta.

TABLE IV.

PRECIPITATION DATA, IN INCHES, FOR THE DIFFERENT STATIONS.

AVERAGE PRECIPITATION.

Station	Length of Record, Yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Wauneta[1]	25	0.26	0.69	1.03	2.04	2.54	3.34	2.47	2.74	1.35	1.13	0.39	0.57	18.55
McCook[2]	14	0.21	0.62	0.73	1.89	2.82	3.29	3.09	2.55	1.72	1.03	0.56	0.57	19.08
Holdrege	20	0.41	0.90	1.02	2.77	4.17	3.71	3.19	3.08	2.07	1.59	0.63	0.70	24.24
Hastings	22	0.44	1.05	1.13	2.77	3.64	4.24	3.62	3.59	2.73	2.02	0.80	0.83	26.87
Lincoln	31	0.62	0.70	1.33	2.77	4.25	4.32	3.83	3.71	2.64	1.82	0.85	0.67	27.51
W. Water	37	0.89	1.04	1.40	2.49	4.19	4.86	3.71	3.88	3.14	2.34	1.24	1.01	30.19

HIGHEST PRECIPITATION RECORDED SINCE 1894.

Station	Length of Record, Yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Wauneta	20	0.80	2.00	3.50	4.05	5.50	7.16	9.38	5.78	3.80	3.90	2.15	3.25	32.24
McCook	20	0.70	2.32	2.85	4.96	6.87	5.63	10.86	4.60	4.53	4.65	2.02	3.19	33.97
Holdrege	20	0.90	2.20	4.25	7.90	12.36	11.83	7.15	6.19	5.05	4.35	2.58	4.19	40.21
Hastings	20	1.25	2.50	3.02	9.26	10.92	7.91	10.62	9.86	6.87	5.82	3.32	4.93	39.01
Lincoln	20	1.15	2.13	3.67	5.11	10.72	11.24	11.35	14.21	7.60	3.62	7.14	4.03	41.22
W. Water	20	2.16	2.83	3.62	4.42	11.45	12.24	10.26	10.00	9.10	3.91	9.20	3.96	41.09

LOWEST PRECIPITATION RECORDED SINCE 1894.

Station	Length of Record, Yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Wauneta	20	0	0	0	0.12	0.20	0.65	0.73	0.30	0	0	0	0	13.13
McCook	20	0	0	0	0.05	0	0.66	0.40	0.36	0.20	T	0	0	9.34
Holdrege	20	T	T	0	T	0.30	0.85	0.50	0.95	0.25	0	0	0	16.26
Hastings	20	T	T	0.16	0.36	0.64	0.38	0.55	0.79	0.60	T	0.04	T	18.81
Lincoln	20	0.07	0.07	0.10	0.02	0.96	0.56	1.05	0.31	0.39	0.05	0.03	0.02	16.38
W. Water	20	0.10	0.10	0.10	0.18	0.55	0.39	0.73	1.25	0.38	0.11	T	0.09	21.06

AVERAGE NUMBER OF DAYS WITH .01 INCH OR MORE OF PRECIPITATION.

Station	Length of Record, Yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Wauneta	12	1	3	3	5	7	8	6	6	4	3	2	3	51
McCook	20	2	3	3	5	5	7	5	6	3	2	1	2	44
Holdrege	23	2	3	2	4	6	7	6	5	4	3	2	3	47
Hastings	20	3	4	4	7	9	10	7	7	5	4	2	3	65
Lincoln	27	4	5	7	8	12	10	9	9	7	6	4	5	86
W. Water	28	5	6	7	9	11	11	8	8	7	6	3	4	85

[1] Data previous to November 1, 1901, from Ough, 10 miles north of Wauneta.

[2] The mean for McCook for 30 years, using the record from 1882 to 1890 at Red Willow and that from 1892 to 1895 at Indianola, is 18.83 inches. The monthly means are all very similar to those here given.

The drouth frequency during the crop-growing season increases quite uniformly from east to west. Defining a *drouth period* as 30 consecutive days or more in which precipitation to the amount of 0.25 inch does not occur, the United States Weather Bureau has recently shown that the total number of drouth periods between March 1 and September 30 for the 20-year period, 1895 to 1914, inclusive, is 15 at Lincoln and 30 near the western edge of the loess.[1]

[1] Chart in National Weather and Crop Bulletin, May 5, 1915.

TABLE V.

RELATION OF THE ANNUAL PRECIPITATION, YEAR BY YEAR, TO THE NORMAL (= 100).

Station	Wauneta[1]	McCook	Holdrege	Hastings	Lincoln	W.Water
Normal, in inches	18.55	18.83	24.24	26.87	27.51	30.19
1895............	90	[2]98	88	90	60	70
1896............	71	107	124	127	138	128
1897............	113	109	119	125	93	77
1898............	113	97	75	93	102	89
1899............	66	73	[4]114	70	82	101
1900............	81	75	[5]104	103	123	114
1901............	104	105	92	85	80	83
1902............	...	135	[6]155	145	150	135
1903............	...	118	[7]146	137	126	106
1904............	134	112	[8]101	85	101	81
1905............	174	178	166	137	129	118
1906............	130	108	127	87	124	79
1907............	109	101	94	83	99	103
1908............	134	[3]95	113	119	130	122
1909............	99	..	90	90	126	136
1910............	76	49	77	84	114	79
1911............	101	64	90	89	89	84
1912............	108	77	73	95	81	89
1913............	86	..	83	89	95	108
1914............	93	96	67	86	145	89

[1] The record previous to November 1, 1901, kept at Ough, 10 miles south of Wauneta.
[2] For Bartley, 17 miles to the east.
[3] Datum for February from Culbertson, 12 miles to the west.
[4] Data for June and August from Kearney, 24 miles northeast.
[5] Datum for March from Kearney, 24 miles northeast.
[6] Datum for September from Kearney, 24 miles northeast.
[7] Data for March and November from Kearney, 24 miles northeast.
[8] Datum for June from Kearney, 24 miles northeast.

The relation of the annual precipitation to the normal at the different stations since 1894 is shown in Table V. The data for the years previous to 1895 are, in the case of so many of the stations, either missing or so incomplete that they do not permit of comparisons. The greatest departures shown are +78 per cent at McCook in 1905, and –40 per cent at Lincoln in 1895. Neither the greatest departures from the normal, nor the relative frequency of the years with an excess or a deficiency of precipitation (Table VI) shows any distinct relation to the longitude.

The average annual snowfall is a little less than 24 inches, it being about one inch heavier in the west than in the east. "As a rule snow covers the ground but a few days at a time after each snow storm, and the ground is covered with snow less than half of the time even during the months of the heaviest snowfall."[1] Much of the snow is swept by

[1] Loveland, G. A., Summary of Climatological Data for the United States, Sec. 37, Southern Nebraska, p. 1.

high winds into the depressions, and so contributes but little to the supply of soil moisture of the land upon which it falls. The snowfall exerts little effect upon the leaching of the soil, although agriculturally, as in the wintering of fall-sown grains, it may be very important.

TABLE VI.

THE RELATIVE FREQUENCY OF THE YEARS WITH PRECIPITATION BELOW OR ABOVE NORMAL.

Per Cent. of Normal	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	W.Water %
Below 71	6	12	5	5	5	5
71 to 90	28	16	35	50	20	45
91 to 110	33	48	20	15	25	20
111 to 130	16	12	25	15	35	20
131 to 150	11	6	5	15	15	10
Above 150	6	6	10	0	0	0

The prevailing winds are from the south or southeast during the growing season and from the northwest or north during the rest of the year. An accurate record of the velocity has been kept at only one of the six stations mentioned in Table I, viz. Lincoln. However, records are available for two other stations, Omaha and North Platte, both in the loess region, the former being about 30 miles northeast of Weeping Water and with a similar normal annual precipitation (30.66 inches) and the latter 65 miles north of McCook with a normal precipitation of 18.86 inches. At Omaha the anemometer is placed at an elevation of 121 feet, at Lincoln of 84 and at North Platte of 51. At the last the station is located in the valley of the Platte River and for this reason the velocity may be considerably lower than on the surrounding plains. An experimental substation of the University of Nebraska is situated about four miles south of North Platte and here, since 1907, a very complete meteorological record has been kept, the instruments being placed on the exposed plain at an elevation of 2985 feet, about 108 feet above the United States Weather Bureau station in the valley. Here the anemometer is two feet above the surface of the ground. The record for six months, April to September, inclusive, for the years 1908 to 1914, which has been furnished us by Mr. W. P. Snyder, has been compared with that from the United States Weather Bureau station for the same months. There are slight differences from month to month, but the average difference is very small, it being about 0.2 miles higher at the experimental substation. Accordingly we may safely assume that the data for North Platte reported in Table VII correctly represent the wind velocity near the surface of the ground on the western plains. While the average velocity recorded is 11 miles per hour at Lincoln, 10 at North Platte and 9 at Omaha, it seems probable that near the surface it would at present be

much lower at Lincoln and Omaha, especially on account of the large number of planted trees now growing. However, there appears to be no evidence that the wind velocity near the ground was not comparatively uniform throughout the region under discussion previous to the advent of settlers.

TABLE VII.

AVERAGE HOURLY WIND MOVEMENT (IN MILES PER HOUR).

Station	Length of Record, Yrs.[1]	January	February	March	April	May	June	July	August	September	October	November	December	Annual
North Platte	40	9	9	11	12	12	10	9	9	9	9	9	8	10
Lincoln	20	11	11	13	14	12	10	5	9	10	11	11	10	11
Omaha	43	9	9	10	11	9	8	7	7	8	8	9	9	9

[1] Including 1914.

Data on the relative humidity are available for North Platte, Lincoln and Omaha (Table VIII). The normal is very similar at all three stations, being 71, 70 and 69 per cent, respectively, while the mean at 8 a. m. is 83, 80 and 78 per cent, and that at 8 p. m., 58, 60 and 61 per cent. Occasionally the humidity during the afternoon in summer falls below 10 per cent in the west and 20 per cent in the east. Thus the data show a very slightly greater humidity in the western part of the region than in the eastern. It is of interest in this connection that according to popular opinion in Nebraska the air is very much drier in the western part.

TABLE VIII.

THE MEAN RELATIVE HUMIDITY.

Station	Length of Record, Yrs.[1]	Hour of Observation	January	February	March	April	May	June	July	August	September	October	November	December	Annual
North Platte	27	8 A.M.	83	84	83	80	83	84	85	88	85	83	79	81	83
		8 P.M	69	67	60	51	54	56	54	55	52	54	57	65	58
		Avg.	76	76	72	66	69	70	70	72	68	69	68	73	71
Lincoln	18	8 A.M	86	83	80	75	79	81	80	84	81	79	77	80	80
		8 P.M	67	68	61	52	57	57	55	58	56	58	62	68	60
		Avg.	73	75	70	63	68	69	67	71	68	68	69	74	70
Omaha	27	8 A.M.	81	81	78	73	75	78	77	79	80	76	77	81	78
		8 P.M.	71	69	63	53	55	56	55	57	59	55	62	70	61
		Avg.	76	75	71	63	65	67	66	68	69	65	70	75	69

[1] Including 1914.

The data on the relative insolation are rather too limited to permit of definite deductions. The number of cloudy days is much greater in the east than in the west (Table IX), while the available data show much less difference in the total number of hours of sunshine (Table X), a rather surprising condition. At North Platte it averages 9 per cent more than at Omaha and 3 per cent more than at Lincoln. In this respect Lincoln resembles North Platte more than it does Omaha.

TABLE IX.

AVERAGE NUMBER OF CLEAR, PARTLY CLOUDY AND CLOUDY DAYS FOR THE SEVEN YEARS, 1908 TO 1914.

Station	Clear Days	Partly Cloudy Days	Cloudy Days
North Platte	175	115	75
Lincoln	140	111	114
Omaha	132	115	118

TABLE X.

PERCENTAGE OF POSSIBLE NUMBER OF HOURS OF SUNSHINE FOR THE SEVEN YEARS, 1908 TO 1914.

	North Platte %	Lincoln %	Omaha %
January	64	55	51
February	65	58	54
March	69	68	58
April	67	66	59
May	64	66	60
June	74	73	66
July	78	76	70
August	73	74	66
September	68	63	59
October	66	61	61
November	64	60	53
December	58	56	52
Year	68	65	59

The data on the rate of evaporation from a water surface are scanty. Russell (25, p. 10; 26, p. 558) by applying a formula to observed meteorological conditions calculated the evaporation for the entire year to be 38 or 40 inches in the extreme eastern part of Nebraska, 50 inches in the western and possibly 60 inches in the extreme southwestern corner. These are to be regarded as only rough approximations of the correct values. For Lincoln there is a record for the months of April to October from 1899 to 1909, the average for the six months, April to September inclusive, being 34.8 inches (21). As the average mean temperature, relative humidity and wind velocity for these eleven years are very simi-

lar to the normals based upon the entire record since observations were begun, it is safe to assume that this represents the normal evaporation. At the North Platte substation a record has been kept beginning with 1907. The average for the six months is 45.06 inches. As during this eight-year period both the average mean relative humidity and the average wind velocity have been lower than normal it is not possible to decide just how closely the average for these years represents the actual normal at North Platte, but probably it does not depart widely. The data are reported in Table XI. The two totals 45.06 and 35.93 inches, it should be observed, are not for the entire year, the measurements being made for only the months in which there is little freezing. The evaporation tanks were placed so that the water surface was kept at the level of the ground. The tank at Lincoln was 3 feet square and 10 inches deep, (21, p. 193) and that at North Platte 6 or 8 feet in diameter and 2 feet deep (9, p. 382). The one at Lincoln may have been somewhat protected, by neighboring buildings and trees, from the full sweep of the south and southwest winds, but on the whole the conditions were such as to make the records satisfactorily comparable.

TABLE XI.

EVAPORATION FROM A FREE WATER SURFACE AT NORTH PLATTE AND LINCOLN.

	April Inches	May Inches	June Inches	July Inches	Aug. Inches	Sept. Inches	Tl. 6 mos. Inches
No. Platte, 1907 to 1914	5.92	6.78	8.54	9.00	8.41	6.41	45.06
Lincoln, 1895 to 1910..	4.71	5.85	6.57	7.57	6.39	4.84	35.93

Bigelow (8, p. 5) reports the annual evaporation at Dutch Flats at the western edge of the state, to be 65.67 inches for the years 1909-1910, using a tank 4 feet in diameter. As observations were not made for the winter months the rates for these were found by interpolation.

The relative evaporation from a free-water surface depends upon the intensity of the solar radiation and the cloudiness, as well as upon the temperature, the relative humidity of the air and the wind velocity. Throughout the region under consideration the last three factors are found to be very uniform, while the first also is to be regarded as uniform, but the cloudiness decreases as we proceed from east to west. To this difference in the amount of sunshine we must attribute the observed differences in the rate of evaporation. Although there are no records of the evaporation in the central portion, represented by Hastings and Holdrege, it seems safe to assume that there it is intermediate between that at Lincoln and that at North Platte, while that at both McCook and Wauneta may be considered very similar to that at North Platte.

To summarize the climatic relations we may state that as we proceed from east to west there is experienced a gradual decrease in the total precipitation and in the cloudiness, with an increase in the rate of evaporation from a water surface and in the frequency of drouths, while the distribution of rainfall and snowfall, the temperature conditions, the wind velocity and the relative humidity remain quite uniform.

Hygroscopicity.

As the variations in the hygroscopicity of soils are due to variations in texture a determination of the former serves to indicate the uniformity in texture of a series of samples. This single-valued expression of the relative heaviness of soils was suggested by Hilgard in 1860 (15, p. xi). The simple method of determining this value which he later designates the "hygroscopic coefficient" (16, p. 16; 17, p. 17)—the percentage of water absorbed by a dry soil from a saturated atmosphere—probably serves quite as well as the more complicated and time-consuming method later developed by Rodewald and Mitscherlich (24). Briggs and McLane (10; 11, p. 140) have introduced a somewhat similar method of expressing the relative texture of soils as a single factor—the "moisture equivalent," defined as the "maximum percentage of moisture a soil can retain in opposition to a centrifugal force equal to 1000 times the force of gravity." Briggs and Shantz (12, p. 64) have concluded that this may serve as an indirect method for the determination of the hygroscopic coefficient, the latter being 0.37 times the moisture equivalent. This method may have some advantages in convenience of execution, the absence of any need of a constant-temperature room, the lesser skill required on the part of the operator and a somewhat closer concordance of duplicate determinations, but these may be in many cases more or less completely offset by the cost of the apparatus required and the difficulties in installation. Further the moisture equivalent in itself expresses only the relative texture while the hygroscopic co-efficient does this quite as well, and at the same time indicates the lower limit of moisture available for the support of life of other than strictly xerophytic plants (1).

The data reported in Tables XII and XIII are the averages of concordant duplicate determinations made by exposing the air-dried soil in a layer *ca* 1 mm. in thickness to a saturated atmosphere for 24 hours, the temperature of the air not varying more than 1°C during the period.

In Table XII there are reported the hygroscopic coefficients of the foot sections from each of the thirty fields, and in Table XIII the averages for the foot levels of the different areas, each value in the latter table thus representing a composite sample from 50 borings and also the average of 10 determinations. In Table XIV are reported the averages of the coefficients for the six-foot sections from the different fields, each value here representing a composite of 60 individual samples and the average of 12 determinations.

TABLE XII.

HYGROSCOPIC COEFFICIENTS OF THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
WAUNETA.						
1	9.9	9.0	8.7	7.9	9.8	9.1
2	10.3	9.3	9.2	9.0	10.2	9.6
3	10.8	9.6	8.9	9.4	9.7	9.7
4	10.7	10.3	9.5	9.4	9.7	9.9
5	9.7	9.0	9.9	7.8	8.8	9.0
6	8.8	7.6	9.7	6.9	8.4	8.3
Average	10.0	9.1	9.3	8.4	9.4	9.2
McCOOK.						
1	10.6	9.6	10.0	10.3	9.6	10.0
2	11.6	11.0	10.1	11.2	10.8	10.9
3	10.9	11.8	9.8	10.7	10.1	10.7
4	9.5	10.5	8.9	10.2	9.3	9.7
5	9.0	10.3	8.5	9.1	8.7	9.1
6	9.6	10.4	8.2	8.9	8.5	9.1
Average	10.3	10.6	9.2	10.1	9.5	9.9
HOLDREGE.						
1	10.6	10.0	9.5	10.4	9.9	10.1
2	11.3	11.0	10.3	11.9	11.5	11.2
3	10.8	11.0	11.7	11.4	11.8	11.3
4	9.6	10.1	10.2	10.0	10.9	10.2
5	8.8	9.1	9.7	9.3	10.8	9.5
6	8.5	9.0	9.5	8.8	11.0	9.4
Average	10.0	10.0	10.1	10.3	11.0	10.3
HASTINGS.						
1	9.4	9.1	10.3	9.1	10.0	9.6
2	11.4	11.2	11.4	12.0	11.9	11.6
3	12.8	11.7	12.0	13.3	12.4	12.4
4	11.1	11.2	11.0	11.6	10.5	11.1
5	10.7	10.4	10.5	11.3	10.6	10.7
6	10.8	10.1	10.4	11.1	11.0	10.7
Average	10.9	10.6	10.9	11.4	11.1	11.0
LINCOLN.						
1	10.9	12.2	11.7	13.4	11.7	12.0
2	14.4	15.1	13.8	15.2	13.5	14.4
3	14.3	14.0	12.5	14.1	13.1	13.6
4	13.6	13.2	12.2	13.9	12.7	13.1
5	13.2	13.1	12.2	12.5	12.6	12.7
6	12.8	13.0	12.3	12.4	12.7	12.6
Average	13.2	13.4	12.5	13.6	12.7	13.1
WEEPING WATER.						
1	12.0	12.4	12.6	12.0	11.6	12.1
2	13.3	13.7	14.4	13.4	13.5	13.7
3	14.4	13.8	14.1	13.6	13.9	14.0
4	12.8	13.1	13.8	12.6	12.8	13.0
5	12.6	12.5	13.4	12.5	12.2	12.6
6	12.3	12.4	13.2	12.6	12.2	12.5
Average	12.9	13.0	13.6	12.8	12.7	13.0

TABLE XIII.

HYGROSCOPIC COEFFICIENTS OF THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

Depth Ft.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg. Wtr.	Average
1	9.1	10.0	10.1	9.6	12.0	12.1	10.5
2	9.6	10.9	11.2	11.6	14.4	13.7	11.9
3	9.7	10.7	11.3	12.4	13.6	14.0	11.9
4	9.9	9.7	10.2	11.1	13.1	13.0	11.1
5	9.0	9.1	9.5	10.7	12.7	12.6	10.6
6	8.3	9.1	9.4	10.7	12.6	12.5	10.5
Average	9.2	9.9	10.3	11.0	13.1	13.0	11.1

The hygroscopicity is, on the whole, strikingly uniform, both from field to field in any one area and from the surface downward in the same field. It is lowest in the two western areas, in the fields of which it is similar, and highest in the two eastern in which also it is similar. Considering the six depths from the individual fields it is seen to show a maximum in either the second or third foot in 28 of the fields, while in the other two—II and III at Wauneta—it is higher in the fourth foot, but by less than 1 per cent. Comparing the values for these two feet it will be seen that there is no regularity, the maximum being shown in the second foot of all the Lincoln field, and in the third foot of all those at Hastings, while in each of the four other areas some fields show the maximum in the second and others in the third foot. The average for all thirty fields is 11.9 for both the second and the third foot. The values for the fifth foot are in general practically the same as for the sixth. The minimum value in the three eastern areas is found in the first foot, and in the three western in the sixth.

TABLE XIV.

AVERAGE HYGROSCOPIC COEFFICIENTS FOR THE DIFFERENT FIELDS.

Field No.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg. Wtr.
I	10.0	10.3	10.0	10.9	13.2	12.9
II	9.1	10.6	10.0	10.6	13.4	13.0
III	9.3	9.2	10.1	10.9	12.5	13.6
IV	8.4	10.1	10.3	11.4	13.6	12.8
V	9.4	9.5	11.0	11.1	12.7	12.7
Average	9.2	9.9	10.3	11.0	13.1	13.0

If we compare the averages for the five fields (Table XIV) it will be seen that those for Weeping Water are similar to those for Lincoln, the maximum value for the ten fields being 13.6 and the minimum 12.5; the Hastings fields all show lower values, from 10.6 to 11.4, while those for Holdrege, from 10.0 to 11.0, are similar; the fields at McCook, 9.2 to 10.6, and at Wauneta, 8.4 to 10.0, have averages which are slightly lower,

but three of the McCook and one of the Wauneta fields show values practically the same as four of those at Holdrege. The uniformity may be well illustrated by pointing out that, in estimating the free moisture in the first six feet of soil in any one of the ten fields in the two eastern areas, it would give entirely satisfactory results to employ the average value, 13.0, instead of using the values actually found for the different fields. For those at Hastings we could use 11.0, and for those at Holdrege and McCook, 10.0. The maximum difference between two fields in the same area is shown at Wauneta where Field IV, which is at the actual border of the loess (Plate III, Fig. 1), the samples being collected a quarter of a mile from the edge, shows a lower value than any other field.

The uniformity in texture of the loess is illustrated by the data in Table XV from a single ranch near Madrid, the samples being taken from a type of soil which has later been mapped by the Bureaus of Soils of the United States Department of Agriculture as Sidney Silt Loam, "the weathered product of one of the late Tertiary deposits."[1]

TABLE XV.

HYGROSCOPIC COEFFICIENTS OF TEN SETS OF SOIL SAMPLES FROM A SINGLE RANCH NEAR MADRID, NEBRASKA.

Depth Ft.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
1	7.8	8.5	8.0	7.5	2.0	5.9	8.5	7.0	5.3	1.9
2	10.4	9.8	9.8	10.5	2.8	6.3	10.2	7.8	5.1	1.8
3	10.2	9.8	11.3	9.2	2.5	6.4	12.4	9.3	3.3	1.7
4	7.0	8.3	7.7	6.9	4.5	7.1	13.1	13.0	3.0	1.5
5	7.0	6.9	6.4	6.6	5.9	7.7	12.2	14.2	3.0	1.8
6	7.8	7.4	6.3	6.9	6.7	9.3	9.0	12.8	1.9	1.9

The proportion of organic matter in the surface foot is highest in the fields of the eastern areas, those in which, as above mentioned, the hygroscopic coefficient shows a minimum in the surface foot. This would suggest that the organic matter exerts little, if any, influence in increasing the hygroscopicity. This view is confirmed by the data presented in Table XVI, giving the hygroscopic coefficients for the different inch sections from each of the areas. From Table XXIX below it will be seen that the organic matter decreases rapidly from the surface downward, the range exceeding 100 per cent for each of the areas. The hygroscopic coefficient, on the other hand varies but little and tends to show an increase, rather than a decrease, from the surface downward. Either the organic matter exerts no effect upon the hygroscopicity, or, as seems more probable, the soil of the first foot, as we proceed from the surface downward, increases in fineness of texture to such an extent that it more than counterbalances the influence of the decrease in organic matter.

[1] *Bur. Soils—1913—Reconnoissance Survey of Western Nebraska, U. S. Dept. Agr., Bur. Soils, Field Operations of 1911.*

TABLE XVI.

HYGROSCOPIC COEFFICIENTS OF THE DIFFERENT INCH SECTIONS FROM THE DIFFERENT AREAS. EACH IS A COMPOSITE OF 100 OR MORE INDIVIDUAL SAMPLES.

Depth In.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	8.5	8.5	10.9	10.9	11.5	11.5	10.3
2	8.2	8.3	10.3	9.7	11.2	11.0	9.8
3	8.2	8.4	9.9	8.9	11.0	11.0	9.6
4	8.3	8.3	9.5	8.5	11.1	11.1	9.5
5	8.2	8.7	9.4	8.3	11.4	11.2	9.5
6	8.6	9.3	9.4	9.0	11.8	11.2	9.9
7	8.7	9.5	9.7	9.5	11.9	11.5	10.1
8	8.8	9.8	9.9	9.5	12.1	12.1	10.4
9	8.6	9.9	10.0	9.5	13.0	12.3	10.6
10	8.8	10.3	10.9	9.7	12.6	12.6	10.8
11	9.0	10.3	10.2	10.0	12.9	12.5	10.8
12	8.7	10.2	10.2	10.2	13.1	12.8	10.9
Average	8.6	9.3	10.0	9.5	12.0	11.7	10.2

If the hygroscopicity is but little influenced by an increase in the organic matter of the soil while the water-holding capacity is distinctly increased, the effect upon crop growth of this increase will be much greater than would be expected from the relative change in the total water content, as the increase will be confined to the available portion of the soil moisture.

TABLE XVII.

HYGROSCOPIC COEFFICIENTS OF THE DIFFERENT INCH SECTIONS FROM THE FIVE FIELDS NEAR LINCOLN.

Depth In.	Field I	Field II	Field III	Field IV	Field V	Average
1	11.2	10.5	10.9	12.2	11.5	11.3
2	9.3	10.6	11.8	12.5	11.1	11.1
3	8.9	10.7	11.3	12.2	11.1	10.8
4	8.9	11.1	11.7	13.0	11.1	11.2
5	9.2	11.3	11.4	12.6	11.5	11.2
6	9.3	11.4	11.6	12.6	11.8	11.3
7	9.3	11.6	12.1	13.3	11.9	11.6
8	9.5	11.8	12.1	13.6	11.9	11.8
9	9.4	12.5	12.6	14.1	11.8	12.1
10	10.0	12.8	13.2	14.5	12.0	12.5
11	10.0	13.9	13.2	15.1	12.4	12.9
12	10.1	14.7	13.9	14.6	13.6	13.4
Average	9.6	11.9	12.2	13.4	11.8	11.8

Only in the case of the Lincoln area were the field inch-sections subjected to the determination of the hygroscopic coefficient. (Table XVII). It will be seen that there is quite as much difference between the sections from Fields I and IV as between the two most dissimliar sets of area-samples. In these also there is to be found no connection between the relative amounts of organic matter and the hygroscopicity (Table XXVII). The organic carbon in the inch-sections from the individual

fields was not determined but the nitrogen was, and as will be shown below the latter bears an almost constant relation to the former. The inch-samples from Field I show the highest content of nitrogen (Table XXI) but the lowest hygroscopic coefficients, while Field IV in which the latter values are highest is the one next to the lowest in nitrogen—additional evidence of the slight influence of the organic matter upon the hygroscopicity. However, the high hygroscopic coefficients for peat soils, containing from 80 to 95 per cent organic matter, which we have found to be from 50 to 60, indicate that the organic matter should be expected to exert at least a slight effect in the case of the prairie soils.

Nitrogen.

Nitrogen was determined in all the field foot-samples (Table XVIII) and field inch-samples (Table XXI), the average of these furnishing the data for the area samples (Tables XIX and XXII). The average nitrogen content for the six feet of each field is given in Table XX.

In all the fields the nitrogen, as was to be expected, decreases from the surface downward. The few cases in which it is found slightly lower in the fourth or fifth foot than in the sixth, as in Wauneta III and McCook I, may safely be attributed to the experimental error of sampling or of analysis. It decreases from east to west. According to the amount in the surface foot, the fields fall into three groups: one with .125 to .146, another with .164 to .209, and the third with .228 to .245 per cent. All the Wauneta and McCook fields are in the first, those at Holdrege and Hastings in the second and those at Lincoln and Weeping Water in the third. This separation into three groups holds also when we consider the averages of the inch-sections from each field (Table XXI), a distinct set of samples.

On the basis of the nitrogen content of the second foot two groups are recognizable, the one including all the fields of the two eastern areas with .078 to .111 and the other those of the four western with .122 to .171 per cent. While the first foot of the Lincoln fields is similar in nitrogen to that of those at Weeping Water, the second foot is lower in the former than in the latter. In the fields of these two eastern areas the nitrogen in the second foot is similar to that in the first foot of the McCook and Wauneta areas. The differences in the third and lower foot are not sufficient to permit of any grouping of areas, although the nitrogen content is in general higher in the eastern than in the western sub-soils from the same depth.

The differences between areas are not so regular when the averages for the fields are compared (Table XX), Fields II and IV at Hastings, for instance, showing a lower content than II at McCook or III at Wauneta. The differences in the nitrogen content of the first foot in the different areas might be due, partly or wholly, to differences in texture, a coarser

TABLE XVIII.

NITROGEN IN THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

WAUNETA.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.135	.138	.144	.129	.132	.136
2	.080	.078	.092	.082	.079	.082
3	.059	.058	.072	.078	.060	.065
4	.043	.056	.042	.047	.043	.046
5	.033	.035	.049	.039	.036	.038
6	.028	.025	.049	.023	.027	.030
Average	.063	.065	.075	.066	.063	.066

McCOOK.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.143	.146	.138	.143	.125	.139
2	.079	.090	.080	.088	.085	.084
3	.048	.067	.052	.052	.049	.054
4	.036	.049	.037	.036	.034	.038
5	.031	.037	.034	.029	.031	.032
6	.034	.031	.030	.029	.027	.030
Average	.062	.070	.062	.063	.059	.063

HOLDREGE.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.172	.174	.164	.189	.209	.182
2	.089	.098	.111	.104	.103	.101
3	.055	.064	.074	.075	.055	.065
4	.038	.043	.053	.056	.037	.045
5	.031	.038	.040	.032	.027	.034
6	.034	.034	.039	.034	.028	.034
Average	.070	.075	.080	.082	.076	.077

HASTINGS.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.171	.174	.183	.169	.174	.174
2	.095	.095	.102	.093	.104	.098
3	.059	.053	.062	.054	.059	.057
4	.043	.039	.044	.032	.046	.041
5	.032	.029	.041	.025	.040	.033
6	.029	.027	.033	.024	.034	.029
Average	.071	.069	.077	.066	.076	.072

LINCOLN.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.241	.245	.234	.238	.242	.240
2	.122	.145	.124	.122	.133	.129
3	.068	.073	.072	.063	.072	.070
4	.050	.060	.058	.065	.065	.060
5	.045	.047	.043	.040	.036	.042
6	.054	.046	.042	.039	.036	.043
Average	.097	.103	.095	.094	.097	.097

WEEPING WATER.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.228	.232	.242	.243	.237	.236
2	.149	.149	.146	.171	.153	.154
3	.081	.086	.080	.097	.070	.083
4	.053	.053	.052	.073	.064	.059
5	.047	.043	.041	.044	.041	.043
6	.040	.039	.035	.039	.039	.038
Average	.100	.100	.099	.111	.101	.102

TABLE XIX.

NITROGEN IN THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

Depth	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg-Wtr.	Average
Foot	%	%	%	%	%	%	%
1	.136	.139	.182	.174	.240	.236	.185
2	.082	.084	.101	.098	.129	.154	.108
3	.065	.054	.065	.057	.070	.083	.066
4	.046	.038	.045	.041	.060	.059	.048
5	.038	.032	.034	.033	.042	.043	.037
6	.030	.030	.034	.029	.043	.038	.034
Average	.066	.063	.077	.072	.097	.102	.079

soil tending to accumulate less organic matter. However, a comparison of the hygroscopic coefficients for the first foot of the McCook and Hastings fields, makes it evident that the texture does not account for the differences between these in nitrogen; at McCook the hygroscopic coefficient averages higher, while the five fields in that area are lower in nitrogen than those at Hastings. The greater amount of nitrogen is probably due to the greater production of vegetable material, both as aerial portions and as roots, in the eastern areas, which in turn is a consequence of the greater rainfall and lower evaporation.

TABLE XX.

AVERAGE NITROGEN CONTENT OF THE FIRST SIX FEET OF EACH FIELD IN EACH OF THE SIX AREAS.

Field No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	.063	.062	.070	.071	.097	.100
II	.065	.070	.075	.069	.103	.100
III	.075	.062	.080	.077	.095	.099
IV	.066	.063	.082	.066	.094	.111
V	.063	.059	.076	.076	.097	.101
Average	.066	.063	.077	.072	.097	.102

From Table XXI it may be seen that in the first foot the nitrogen in all fields is highest in the first inch, while the amount in the twelfth is approximately half of that in the first.

A fair comparison of the nitrogen content of two fields is difficult, for the reason that if the soil of one is the more compact, the sampling tools will penetrate relatively deeper and as a result the soil sample will show a lower nitrogen content. For this reason, instead of taking the samples that are to be under comparison to the same depth, they should be taken so as to secure the same dry weight of each in a section with the same surface.

To determine the influence of such differences in density upon the found nitrogen content we weighed the samples from all the fields of each of the areas, except the two first sampled—Lincoln and Holdrege. In none of the twenty fields did we find any relation between depth and

TABLE XXI.

NITROGEN IN THE INCH SECTIONS FROM THE SURFACE FOOT OF THE FIVE FIELDS OF EACH AREA.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
			WAUNETA.			
1	.219	.202	.224	.184	.197	.205
2	.192	.183	.169	.151	.169	.173
3	.177	.170	.162	.145	.173	.165
4	.161	.146	.159	.130	.150	.149
5	.145	.131	.140	.114	.142	.134
6	.138	.120	.132	.112	.136	.128
7	.128	.114	.124	.103	.121	.118
8	.120	.108	.117	.103	.114	.112
9	.122	.109	.116	.102	.115	.113
10	.113	.100	.107	.095	.106	.104
11	.105	.093	.103	.088	.102	.098
12	.101	.088	.099	.087	.099	.095
Average	.143	.130	.138	.118	.135	.132
			McCOOK.			
1	.220	.208	.205	.212	.174	.204
2	.157	.184	.169	.165	.151	.165
3	.158	.173	.164	.165	.155	.163
4	.167	.163	.162	.157	.145	.159
5	.153	.150	.145	.148	.133	.146
6	.144	.145	.135	.140	.133	.139
7	.128	.132	.129	.127	.122	.128
8	.115	.120	.119	.116	.109	.116
9	.113	.116	.113	.109	.100	.110
10	.099	.112	.106	.099	.093	.102
11	.094	.104	.097	.096	.087	.096
12	.094	.101	.090	.090	.086	.092
Average	.137	.142	.136	.135	.124	.135
			HOLDREGE.			
1	.238	.391	.361	.318	.305	.323
2	.213	.286	.282	.261	.291	.267
3	.204	.259	.246	.221	.239	.234
4	.182	.229	.206	.200	.215	.206
5	.167	.204	.188	.179	.196	.187
6	.161	.180	.168	.167	.173	.170
7	.139	.172	.158	.155	.158	.156
8	.137	.153	.144	.147	.149	.146
9	.132	.152	.140	.141	.145	.142
10	.122	.142	.134	.135	.141	.135
11	.124	.134	.136	.132	.137	.133
12	.115	.131	.130	.127	.132	.127
Average	.161	.203	.191	.182	.190	.186

TABLE XXI.—(Continued).

HASTINGS.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.287	.312	.350	.409	.411	.354
2	.216	.235	.259	.235	.241	.237
3	.196	.203	.219	.206	.200	.205
4	.182	.184	.195	.185	.181	.186
5	.170	.176	.183	.175	.169	.175
6	.159	.164	.168	.166	.154	.162
7	.154	.161	.165	.156	.146	.156
8	.149	.155	.158	.148	.138	.150
9	.142	.147	.150	.147	.135	.144
10	.140	.142	.145	.143	.130	.140
11	.136	.138	.142	.141	.127	.137
12	.131	.134	.138	.137	.122	.132
Average	.172	.179	.189	.187	.180	.181

LINCOLN.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.495	.296	.293	.304	.348	.347
2	.327	.273	.254	.253	.287	.279
3	.299	.255	.235	.240	.265	.259
4	.275	.250	.224	.231	.248	.245
5	.262	.241	.212	.223	.231	.234
6	.253	.229	.205	.211	.215	.223
7	.224	.221	.195	.205	.205	.210
8	.219	.214	.186	.192	.196	.201
9	.217	.202	.176	.184	.184	.193
10	.202	.186	.167	.175	.173	.181
11	.197	.177	.160	.163	.166	.173
12	.185	.168	.148	.159	.154	.163
Average	.260	.226	.205	.212	.223	.225

WEEPING WATER.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.310	.281	.481	.290	.345	.341
2	.267	.266	.390	.275	.288	.297
3	.250	.248	.273	.259	.269	.260
4	.237	.235	.249	.246	.253	.244
5	.225	.230	.235	.237	.240	.233
6	.218	.219	.226	.232	.231	.225
7	.211	.213	.221	.225	.214	.217
8	.202	.209	.212	.215	.204	.208
9	.200	.201	.205	.210	.199	.203
10	.198	.199	.195	.207	.193	.198
11	.190	.185	.186	.203	.187	.190
12	.181	.183	.181	.197	.185	.185
Average	.224	.222	.255	.233	.234	.234

density farther than that, as a rule, the first and second inch sections were lighter than the deeper ones. If the average weight of the 1-3 inch section in the 20 fields be placed at 100, the average weights for the 4-6, 7-9 and 10-12 inch sections would become 111, 110 and 111, respectively. The surface foot of the eastern fields is somewhat denser than that of the western, the relative averages being: Wauneta 94, McCook 90, Hastings

TABLE XXII.

NITROGEN IN THE INCH SECTIONS OF THE SURFACE FOOT OF THE SIX DIFFERENT AREAS.

Depth Inch	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	.205	.204	.323	.354	.347	.341	.296
2	.173	.165	.267	.237	.279	.297	.236
3	.165	.163	.234	.205	.259	.260	.214
4	.149	.159	.206	.186	.246	.244	.198
5	.134	.146	.187	.175	.234	.233	.185
6	.128	.139	.170	.162	.223	.225	.175
7	.118	.128	.156	.156	.210	.217	.164
8	.112	.118	.146	.150	.201	.208	.156
9	.113	.110	.142	.144	.193	.203	.151
10	.104	.102	.135	.140	.181	.198	.143
11	.098	.096	.133	.137	.173	.190	.138
12	.095	.092	.127	.132	.163	.185	.132
Average	.132	.135	.186	.181	.225	.234	.182

110, and Weeping Water 108 (Table XXIII). The greater density of the samples from the eastern fields may be due to differences in moisture content at the time of sampling, the soil of the western areas being dry and that of the eastern more or less moist. In the case of all the Wauneta and McCook fields, of II and V at Hastings, and II, III and V at Weeping Water, samples for moisture determination were taken at the same time as those for chemical analysis. In the first foot of all the fields of the western areas the free water, the difference between the total moisture and the hygroscopic coefficient, lay between 0.0 and 2.0 per cent, while in the five eastern fields mentioned it was 13.4, 9.5, 14.4, 6.8 and 11.6 per cent respectively. When moist the soil tends to permit of a greater compression as the sampling tube is forced in. The difference to be observed among the ten western fields could not have been influenced by the moisture content as this was similar in all. At Hastings all five fields were sampled within less than five days of one another during a period of fair weather following a succession of rains. At Weeping Water the fields were sampled near the end of November, after two months of almost rainless weather; here a difference of 100 per cent in the free water content was not accompanied by a distinct difference in the found density. It may be that the density of the surface foot of the western prairies is less than that of the eastern, but we do not consider our data sufficient to justify any such definite conclusion.

The depth of sampling should vary inversely as the found density. If the depths indicated in Table XXIV had been employed, the average dry weight of the twenty cores from each field used in the preparation of the inch samples would have been practically the same. From the data in Tables XXI and XXIV we can calculate the per cent of nitrogen in the first foot that would have been found if such a method of sampling had

been followed. The extent to which they differ from the averages of the twelve sections given in Table XXI is shown in Table XXV. While in general the difference is not great it is evident that in any fine work the relative weights of the samples under comparison should not be ignored. The importance of this has previously been pointed out (4, 2). It is

TABLE XXIII.

RELATIVE DENSITY OF THE SURFACE FOOT OF SOIL FROM DIFFERENT FIELDS. (AVERAGE OF THE 20 = 100.)

Field No.	Wauneta	McCook	Hastings	Weeping Water
I	93	102	88	101
II	99	98	125	110
III	90	81	127	111
IV	95	83	95	111
V	92	87	115	107
Average	94	90	110	108

TABLE XXIV.

DEPTH IN INCHES TO WHICH THE DIFFERENT FIELDS SHOULD HAVE BEEN SAMPLED IN ORDER TO SECURE THE SAME WEIGHT OF SOIL FROM EACH.

Field No.	Wauneta	McCook	Hastings	Weeping Water
I	10.5	9.5	11.0	9.5
II	10.0	10.0	8.0	9.0
III	11.0	12.0	7.5	9.0
IV	10.5	11.5	10.5	9.0
V	11.0	11.0	8.5	9.0

readily apparent that the soil of a pasture field may be expected to show a greater density than that of a meadow, and, consequently, if both are sampled to the same depth, also a lower nitrogen content, although the two may be equally rich in this constituent.

The differences above are quite similar to those shown between the nitrogen content of the composite of 10 individual samples taken with an auger and that secured by the tube from the same field (Table XXVI).

TABLE XXV.

CHANGE IN THE NITROGEN CONTENT FOUND FOR THE FIRST FOOT THAT WOULD HAVE BEEN CAUSED BY USING THE SAME WEIGHT, INSTEAD OF THE SAME DEPTH OF SOIL.

Field No.	Wauneta	McCook	Hastings	Weeping Water
I	.005	.011	.004	.009
II	.008	.008	.019	.010
III	.003	.000	.025	.021
IV	.004	.002	.007	.010
V	.003	.011	.021	.016

TABLE XXVI.

DIFFERENCES IN NITROGEN CONTENT FOUND IN THE TWO SETS OF SAMPLES FROM THE SAME FIELD. A DEFICIENCY FOR THE AVERAGE OF THE INCH SECTIONS IS INDICATED BY THE MINUS SIGN.

Field No. No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	.006	—.006	—.011	.001	.019	—.004
II	—.007	—.004	.029	.005	—.019	—.010
III	—.007	—.002	.027	.006	—.029	.013
IV	—.011	—.008	—.007	.018	—.026	—.010
V	.003	—.001	—.019	.006	—.019	—.001

Organic Carbon.

The organic carbon was determined by combustion with copper oxide in a current of oxygen, the 10-gram sample of soil having first been treated with phosphoric acid solution and evaporated to dryness. It was found desirable in the case of the calcareous subsoils to repeat the treatment with phosphoric acid in order to ensure the full decomposition of carbonates. Analyses were made of all the field foot-samples (Table XXVII), the averages of which give the data for the area foot-samples (Table XXVIII), and also of the area inch-samples (Table XXIX). The average carbon content for the six foot-sections from each field is given in Table XXX.

In all the areas the carbon decreases from the surface downward, both in the foot and in the inch sections. As was the case with the nitrogen content, the fields may be placed in three groups according to the amount of carbon in the surface foot. The Wauneta and McCook fields have between 1.49 and 1.81 per cent, the Holdrege and Hastings fields between 1.93 and 2.50, and those of the eastern two areas between 2.76 and 3.07. On the basis of the composition of the second foot only two distinct groups, as with the nitrogen, are recognizable. For the third, fourth, fifth and sixth feet there is no grouping, the highest average content being shown by the two outer groups, that for the four feet for Weeping Water being .44 per cent against .42 for Wauneta and that for the fourth to sixth foot being .35 and .32 per cent, respectively. The fields of the two eastern areas show the same relative differences in the carbon as in the nitrogen content, they being similar in the first but those at Lincoln having, with one exception, a distinctly smaller amount in the second foot.

Again, as with nitrogen, the differences are not so regular when we consider the average for the six feet of the different fields (Table XXX), the distinction between the western and the central areas disappearing.

The rate of decrease in the carbon content from the first to the twelfth inch in the surface foot is quite similar in all the areas.

TABLE XXVII.

ORGANIC CARBON IN THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

WAUNETA.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	1.67	1.64	1.70	1.54	1.49	1.61
2	.83	.75	.91	.77	.73	.80
3	.55	.65	.67	.77	.50	.63
4	.38	.59	.51	.45	.36	.46
5	.29	.28	.50	.25	.30	.32
6	.24	.21	.46	.18	.22	.26
Average	.66	.69	.79	.66	.60	.68

McCOOK.

1	1.63	1.81	1.66	1.72	1.41	1.65
2	.71	.92	.77	.88	.70	.80
3	.42	.72	.53	.55	.58	.56
4	.32	.45	.32	.29	.31	.34
5	.25	.35	.27	.22	.33	.28
6	.23	.22	.22	.19	.20	.21
Average	.59	.74	.63	.64	.59	.64

HOLDREGE.

1	2.10	2.16	2.24	2.32	2.50	2.26
2	.93	1.05	1.22	1.10	1.11	1.08
3	.49	.56	.75	.69	.50	.60
4	.33	.36	.46	.47	.27	.38
5	.21	.29	.29	.21	.21	.24
6	.21	.23	.26	.19	.15	.21
Average	.71	.78	.87	.83	.79	.79

HASTINGS.

1	2.02	1.97	2.19	1.93	2.19	2.06
2	1.04	1.01	1.14	.93	1.13	1.05
3	.64	.56	.56	.44	.67	.57
4	.36	.32	.35	.21	.42	.33
5	.23	.20	.29	.14	.33	.24
6	.16	.15	.20	.14	.25	.18
Average	.74	.70	.79	.63	.83	.74

LINCOLN.

1	2.87	2.88	2.77	2.88	2.98	2.88
2	1.32	1.32	1.19	1.31	1.46	1.32
3	.66	.62	.61	.63	.77	.66
4	.34	.36	.34	.31	.38	.35
5	.22	.25	.28	.23	.27	.25
6	.19	.23	.22	.25	.24	.23
Average	.93	.94	.90	.94	1.02	.95

WEEPING WATER.

1	2.82	2.76	2.95	3.07	2.85	2.89
2	1.76	1.74	1.43	2.07	1.75	1.75
3	.80	.73	.59	1.02	.87	.80
4	.47	.48	.45	.56	.44	.48
5	.27	.27	.23	.30	.25	.26
6	.24	.22	.16	.24	.20	.21
Average	1.06	1.03	.97	1.21	1.06	1.06

TABLE XXVIII.

ORGANIC CARBON IN THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	1.61	1.65	2.26	2.06	2.88	2.89	2.22
2	.80	.80	1.08	1.05	1.32	1.75	1.14
3	.63	.56	.60	.57	.66	.80	.64
4	.46	.34	.38	.33	.35	.48	.39
5	.32	.28	.24	.24	.25	.26	.26
6	.26	.21	.21	.18	.23	.21	.22
Average	.68	.64	.79	.74	.95	1.06	.81

TABLE XXIX.

ORGANIC CARBON IN THE DIFFERENT INCH SECTIONS OF THE SURFACE FOOT OF THE SIX DIFFERENT AREAS.

Depth Inch	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	2.85	2.42	4.60	4.52	4.70	4.52	3.93
2	2.11	1.94	3.50	3.17	3.65	3.71	3.01
3	1.85	1.90	2.87	2.58	3.31	3.25	2.63
4	1.67	1.82	2.45	2.28	3.12	3.07	2.40
5	1.48	1.65	2.17	2.03	2.84	2.83	2.17
6	1.46	1.54	2.01	1.86	2.74	2.65	2.04
7	1.31	1.44	1.77	1.79	2.50	2.37	1.86
8	1.27	1.34	1.72	1.67	2.39	2.34	1.79
9	1.23	1.26	1.62	1.59	2.31	2.29	1.72
10	1.14	1.16	1.55	1.53	2.08	2.18	1.61
11	1.03	1.07	1.49	1.52	1.97	2.14	1.54
12	1.03	1.00	1.45	1.45	1.89	2.09	1.48
Average	1.54	1.54	2.25	2.17	2.79	2.79	2.18

TABLE XXX.

AVERAGE CONTENT OF ORGANIC CARBON IN THE FIRST SIX FEET OF EACH FIELD IN EACH OF THE SIX AREAS.

Field No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	.66	.59	.71	.74	.93	1.06
II	.69	.74	.78	.70	.94	1.03
III	.79	.63	.87	.79	.90	.97
IV	.66	.64	.83	.63	.94	1.21
V	.60	.59	.79	.83	1.02	1.06
Average	.68	.64	.80	.74	.95	1.07

Carbon-Nitrogen Ratio.

The ratio of the organic carbon to the nitrogen shows some interesting differences. In the surface foot the ratio is everywhere very similar, it varying only between 11.2 and 13.6 for the field samples (Table XXXI). It is independent of the aridity. In the second foot it is lower than in the surface foot, and while it shows a tendency to be lower in the western than in the eastern areas this is not an area characteristic as may be seen from the data for the individual fields. While in most cases the third foot shows a lower ratio than the second, and the fourth one still lower, in neither is an area characteristic exhibited. In the fifth and sixth feet the ratio is still lower, it decreasing less in general in the western areas. As a result of this an accurate analysis of samples from the western, central and eastern areas might be expected to show characteristic differences regularly when the samples analyzed were composites of a very large number of individual samples.

Even in the surface foot the differences in the Carbon-Nitrogen ratio are small (Table XXXIII). It decreases from a maximum varying from 11.9 to 14.3 in the surface inch to a minimum of 10.4 to 11.4 in the twelfth.

Volatile Matter and Water of Constitution.

The *volatile matter* as ordinarily determined (6, p. 14) is reported in Table XXXIV together with the organic matter (organic C $\times$ 1.724) and the so-called "water of constitution," which represents the difference between the two preceding values. Instead of the abitrary 1.724, probably different factors should be used for the different depths; also, judging from the Carbon-Nitrogen ratio, it should not be considered as a constant for even the same depth of subsoil in different fields. However, as nothing more serviceable is as yet available the same factor has been used throughout in calculating the organic matter from the organic carbon. The found percentage of "water of constitution," which in this case represents the water not expelled at 110° C but driven off below a dull red heat, will be affected by any inaccuracy in the determination of organic carbon. As it is derived chiefly from the hydrated silicates and oxides it may be expected to vary as the sum of the alumina and the iron oxide. Considering the average of the six foot depths, it is seen to increase slightly from west to east and in each area to show a maximum in the second or third foot.

The variations are closely concordant with those of the hygroscopicity (Table XXXV). The average ratio of hygroscopic coefficient to water of constitution is 3.43. This ratio varies only between 3.27 and 3.65 for areas, and between 3.40 and 3.53 for the different levels.

TABLE XXXI.

RATIO OF ORGANIC CARBON TO NITROGEN IN THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

WAUNETA.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	12.4	11.9	11.8	12.0	11.3	11.9
2	10.4	9.6	9.9	9.4	9.3	9.7
3	9.3	11.2	9.3	9.8	8.3	9.6
4	8.9	10.5	12.1	9.6	8.4	9.9
5	8.8	8.0	10.2	6.4	8.4	8.4
6	8.6	8.4	9.4	7.8	8.1	8.5
Average	9.7	9.9	10.5	9.2	9.0	9.7

McCOOK.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	11.4	12.4	12.0	12.0	11.3	11.8
2	9.0	10.2	9.7	10.0	8.3	9.4
3	8.8	10.7	10.2	10.6	10.7	10.2
4	8.9	8.2	8.7	8.1	9.1	8.6
5	8.1	9.5	8.0	7.6	10.6	8.8
6	6.9	7.1	7.3	6.6	7.4	7.1
Average	8.8	9.7	9.3	9.1	9.6	9.3

HOLDREGE.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	12.2	12.4	13.6	12.3	12.0	12.5
2	10.4	10.7	10.9	10.6	10.7	10.7
3	8.9	8.8	10.1	9.2	9.1	9.2
4	8.7	8.4	8.7	8.4	7.3	8.3
5	6.8	7.6	7.2	6.5	7.7	7.2
6	6.2	6.8	6.7	5.6	4.4	6.0
Average	8.9	9.1	9.5	8.8	8.5	9.0

HASTINGS.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	11.8	11.3	11.9	11.4	12.6	11.8
2	11.0	10.6	11.2	10.0	10.8	10.7
3	10.8	10.2	9.0	8.2	11.3	9.9
4	8.4	8.2	8.0	6.6	9.1	8.1
5	7.2	6.9	7.1	5.6	8.3	7.0
6	5.5	5.6	6.1	5.8	7.3	6.1
Average	9.1	8.8	8.9	7.9	9.9	8.9

LINCOLN.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	11.9	11.8	11.8	12.1	12.3	12.0
2	10.8	9.1	9.6	10.7	11.0	10.2
3	9.7	8.5	8.5	10.0	10.7	9.5
4	6.7	6.0	5.9	4.8	5.9	5.9
5	4.9	5.3	6.5	5.8	7.5	6.0
6	3.5	5.0	5.2	6.4	6.7	5.4
Average	7.9	7.6	7.9	8.3	9.0	8.2

WEEPING WATER.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	12.3	11.9	12.2	12.6	12.0	12.2
2	11.8	11.7	9.8	12.1	11.4	11.4
3	9.9	8.5	7.4	10.5	12.4	9.5
4	8.9	9.1	8.6	7.7	6.9	8.2
5	5.7	6.3	5.6	6.8	6.1	6.1
6	6.0	5.7	4.6	6.4	5.1	5.6
Average	9.1	8.9	8.0	9.3	9.0	8.8

TABLE XXXII.

RATIO OF ORGANIC CARBON TO NITROGEN IN THE DIFFERENT FOOT SECTIONS OF THE SIX DIFFERENT AREAS.

Depth Ft.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	11.9	11.8	12.5	11.8	12.0	12.2	12.0
2	9.7	9.4	10.7	10.7	10.2	11.4	10.3
3	9.6	10.2	9.2	9.9	9.5	9.5	9.6
4	9.9	8.6	8.3	8.1	5.9	8.2	8.2
5	8.4	8.8	7.2	7.0	6.0	6.1	7.6
6	8.5	7.1	6.0	6.1	5.4	5.6	6.6
Average	9.7	9.3	9.0	8.9	8.2	8.8	9.1

TABLE XXXIII.

RATIO OF ORGANIC CARBON TO NITROGEN IN THE DIFFERENT FOOT SECTIONS OF THE SURFACE FOOT OF THE SIX DIFFERENT AREAS.

Depth In.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	14.3	11.9	14.3	12.8	13.8	13.3	13.4
2	12.2	11.8	13.1	13.4	13.1	12.5	12.8
3	11.2	11.7	12.3	12.6	12.8	12.5	12.3
4	11.2	11.5	11.9	12.3	12.7	12.5	12.0
5	11.0	11.3	11.6	11.6	12.1	12.1	11.6
6	11.4	11.1	11.8	11.5	12.3	11.8	11.6
7	11.1	11.3	11.3	11.5	11.9	10.9	11.3
8	11.3	11.4	11.8	11.1	11.9	11.3	11.5
9	10.9	11.5	11.4	11.0	12.0	11.2	11.3
10	11.0	11.3	11.5	10.9	11.5	11.5	11.3
11	10.5	10.9	11.1	11.1	11.4	11.3	11.0
12	10.6	10.4	11.4	11.0	11.6	11.3	11.0
Average	11.4	11.3	12.0	11.7	12.3	11.9	11.8

Comparison With Chernozem Soils.

The soils of the transition region are, in comparison with the typical Russian Chernozem soils, low in both organic matter and nitrogen. In the surface 4 to 8 inches of the latter, where it has formed upon loess, the organic carbon varies from 3.5 to 6.0 per cent (20, p. 318) and the nitrogen from 0.3 to 0.5 per cent. Both are highest in the central portion of the Chernozem zone and decrease with the approach on one side to the forest regions and on the other to the desert areas. Where the soils have not long been under cultivation these constituents decrease with the depth more or less regularly, although at some distance from the surface there is a rather sharp break, the rate of increase being accelerated.

The two series of analyses from the government of Saratof, given in Table XXVI (20, p. 322) may serve to illustrate the difference in both amount and manner of distribution of the organic matter compared with

TABLE XXXXIV.

VOLATILE MATTER, ORGANIC MATTER AND WATER OF CONSTITUTION IN THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

VOLATILE MATTER.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	5.05	5.71	7.10	6.25	8.44	8.43	6.83
2	4.03	4.52	5.10	5.45	6.68	7.17	5.49
3	4.08	3.74	4.48	4.63	5.25	5.24	4.57
4	3.47	3.44	3.98	4.00	4.22	4.46	3.93
5	2.75	3.28	3.34	3.83	4.07	4.27	3.59
6	2.97	3.00	3.10	3.71	3.90	3.99	3.44
Average	3.72	3.97	4.52	4.64	5.43	5.59	4.64

ORGANIC MATTER (C X 1.724).

1	2.77	2.85	3.90	3.55	4.96	4.98	3.83
2	1.38	1.44	1.86	1.81	2.28	3.02	1.96
3	1.09	.97	1.01	.98	1.14	1.38	1.09
4	.79	.59	.66	.60	.60	.83	.68
5	.55	.48	.41	.41	.43	.45	.45
6	.45	.36	.36	.31	.40	.36	.37
Average	1.17	1.11	1.37	1.28	1.63	1.84	1.40

WATER OF CONSTITUTION.

1	2.28	2.86	3.20	2.70	3.48	3.45	2.99
2	2.65	3.08	3.24	3.64	4.40	4.15	3.53
3	2.99	2.77	3.47	3.65	4.11	3.86	3.48
4	2.68	2.85	3.32	3.40	3.62	3.63	3.24
5	2.20	2.80	2.93	3.42	3.64	3.82	3.14
6	2.52	2.64	2.74	3.40	3.50	3.63	3.07
Average	2.55	2.83	3.15	3.37	3.79	3.76	3.24

TABLE XXXV.

RATIO OF HYGROSCOPIC COEFFICIENT TO WATER OF CONSTITUTION.

Depth Ft.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	3.99	3.50	3.16	3.55	3.45	3.51	3.53
2	3.62	3.54	3.46	3.19	3.27	3.30	3.40
3	3.24	3.77	3.26	3.40	3.31	3.60	3.43
4	3.69	3.40	3.00	3.26	3.59	3.58	3.42
5	4.09	3.25	3.28	3.13	3.52	3.30	3.43
6	3.29	3.45	3.43	3.15	3.63	3.44	3.40
Average	3.65	3.49	3.27	3.28	3.46	3.45	3.43

that in the transition soils. The rate of decrease is similar, but at corresponding depths the amounts are much lower in the latter. The or-

ganic carbon[1] in the first four inches of the Weeping Water and Lincoln areas is barely above the lower limit (3.5 per cent) mentioned above.

The carbon and nitrogen in the Chernozem soils rise and fall together, the ratio being generally somewhat below 11.6 for the surface soil and decreasing from the surface downward (20, p. 323). As this value is based largely upon the analyses of long cultivated soils in which the ratio is perceptibly lower than in virgin soils (3_2, p. 137; 5, p. 161) it is to be regarded as showing no distinct difference from that in the transition soils.

TABLE XXXVI.

COMPARISON OF THE DISTRIBUTION OF ORGANIC CARBON IN CHERNOZEM SOILS WITH THAT IN THE NEBRASKA LOESS SOILS.

Depth	Chernozem Soils from		Transition Soils from	
	Serdobsk %	Atkarsk %	Weeping Water %	Wauneta %
0-2 inches	7.07	....	4.11	2.48
2-4 inches	....	6.50	3.16	1.76
4-6 inches	6.60	....	2.74	1.47
6-8 inches	....	6.50	2.35	1.29
8-10 inches	4.54	4.58	2.24	1.18
2nd foot	3.56	3.66	1.75	.80
3rd foot	2.00	2.08	.80	.63
4th foot	1.03	.80	.48	.46

Unfortunately data from systematic fertilizer experiments on the Nebraska loess are not available, but such as there are, those from scattered trials in cooperation with farmers, leave it an open question whether phosphate fertilizers will at present cause any distinct crop increase. However, there appears no doubt that applications of nitrogen fertilizers would increase crop yields, the inadequacy of the supply of available nitrogen in the eastern areas appearing within 20 or 30 years at the most. In this respect the transition soils appear to differ much from the Russian Chernozem soils, which, as mentioned above (p. 202), long retain their fertility, and, when this declines, show a lack first of phosphoric acid, and only later of nitrogen.

[1] The percentages of organic carbon in the Chernozem soils mentioned in this section have been calculated from the "humus" reported by Kossowitsch, who, like all continental Europeans, employs the term as synonymous with our "organic matter of the soil," determined by combustion with copper oxide. In the United States the term *humus* is commonly used to signify only the alkali-soluble portion, although a few Americans use it to signify the whole of the organic matter. Thus Cameron speaks of "the introduction of humus by a grass crop or a green manure crop." (The Soil Solution, 1911, p. 4.)

[2] In Table IV in the reference the carbon in the soil "in cultivation 21 years, in grass 4 years," was, through typographical error reported as 2.10 per cent instead of 3.10.

Comparison With Arid Soils.

It would be of interest to compare the soils of the different areas, and especially those of the two western semi-arid ones, with the arid soils of the United States, but data on the organic carbon and nitrogen content of the latter are rather too scanty to permit of any satisfactory comparison, Hilgard's and Loughridge's extended studies reporting the humus and the humus-nitrogen instead of the organic matter and the total nitrogen.

However, we have data on the relative "rawness" of the subsoils of all the areas. Hilgard has repeatedly called attention to the lack of this in arid subsoils; "cellars and house foundations are dug, and the material removed, even to the depth of 8 feet, is fearlessly put on the garden and there serves as a new soil on which vegetables and small fruits grow, the first year, as well as ever" (18, p. 166). Still more recently (19, p. 418) he writes: "Such a heap now lying before my eyes,[1] the upper layer of which had eight months before been excavated from a depth of 4 meters and still retained the last rain, shows a thick stand of *grasses*[2] and weeds of all kinds, among them wild oats, radish, mustard, ..."[3]

We have found, both from pot experiments and by observation in different parts of the loess region where considerable areas of subsoil had been deeply exposed by railroad excavations, that inoculated legumes grow almost as well on the subsoils from depths of 3 to 20 feet as on the corresponding black surface soil, but that non-leguminous plants fail to make any satisfactory growth unless treated with a nitrogen fertilizer or preceded by legume crops. The subsoils of the eastern areas appear no more "raw" than do those of the extreme western. Thus in this respect the semi-arid soils, instead of showing a behavior intermediate between that of the arid soils and that of the humid loess soils, strictly resemble the latter.

Summary.

The soils studied represent the first six foot-sections, and also the twelve one-inch sections of the surface foot, from five virgin prairie fields in each of six so-called "areas" in Nebraska, located between the Missouri River and the western limit of the loess, a distance of more than 300 miles, in which, while the temperature conditions, wind velocity and relative humidity, are quite uniform, there is a great range in aridity, the annual precipitation decreasing from more than 30 inches in the east to less

[1] In Berkeley, California.
[2] Italics by the author and not in the original article.
[3] Author's translation from Hilgard, loc. cit.

than 20 in the west, while the relative aridity exhibits a still greater range on account of the increase in the rate of evaporation which accompanies the decrease in precipitation.

The hygroscopicity, as expressed by the hygroscopic coefficient, is strikingly uniform both from field to field in any one area and from the surface downward in the same field. It is lowest in the two western areas and highest in the two eastern. When the different levels from the individual fields are compared, the highest is found in either the second or the third foot, in which two it is very similar. The minimum value is found in the surface foot of the three eastern areas, and in the sixth of the three western. The uniformity within any area is so great that in estimating the free moisture in the first six feet of soil of any field, provided that it be loess, it appears satisfactory to employ simply the average hygroscopic coefficient for all the fields of the area. The effect of the organic matter upon the hygroscopicity is too slight to be detected, a change of even 100 per cent in the content of this being without distinct influence.

The nitrogen content in all the fields decreases from the surface downward. In the surface foot, in which it was determined in each of the twelve inch sections, it decreases steadily, there being in general about half as much in the twelfth as in the first inch section. The nitrogen in the surface foot decreases by about 50 per cent as we pass from the most easterly to the most westerly fields, the difference being such as to permit a definite grouping of the areas. The most easterly areas show as high a content in the second foot as do the most westerly in the first. In this level also there is a decrease from east to west, but it does not show the gradual change exhibited in the first foot. In the still lower levels, third to sixth foot, although the nitrogen in general is higher in the eastern than in the western fields, the differences are small.

The great difference in density of the surface soil from field to field combined with the rapid decrease in nitrogen from the surface downward in virgin prairies, renders satisfactory sampling difficult, which should be carried out in such a way that in sections of like surface equal weights of dry soil are secured.

The organic carbon in the surface foot is very similar in distribution to that of the nitrogen. The amount of the former is approximately 12 times that of the latter, the ratio being uninfluenced by the aridity of the climate. When the inch sections of the surface foot are considered it is seen that the organic carbon decreases slightly more rapidly than does the nitrogen, the average ratio being 13.4 for the first, and 11.3 for the twelfth inch section. In the levels below the first foot also a similar difference in the rate of decrease is observed, the ratio in some cases falling as low as 6.0. The decrease is less rapid in the western than in the east-

ern areas, the average organic carbon content in the fourth, fifth, and sixth feet being higher in the two most westerly areas than in the two most easterly, while that of the nitrogen is lower.

The decrease in nitrogen and organic carbon in the surface soil as we proceed from east to west cannot be explained by the increase in coarseness of texture, but must be attributed to the greater vegetative growth without a correspondingly more rapid decay in the eastern areas.

The water of constitution—the difference between volatile matter and organic matter—decreases from east to west, the variations being concordant with those in the hygroscopicity.

Compared with the Russian Chernozem soils formed on loess the organic carbon and the nitrogen are low both in the surface soil and in the subsoil, the amounts found in the eastern areas being similar to the minima reported for the Chernozem.

The subsoils from the semi-arid areas, in so far as the nitrogen is concerned, in contrast with the arid subsoils, are as "raw" as those from the humid areas, not supporting a satisfactory growth of non-leguminous plants.

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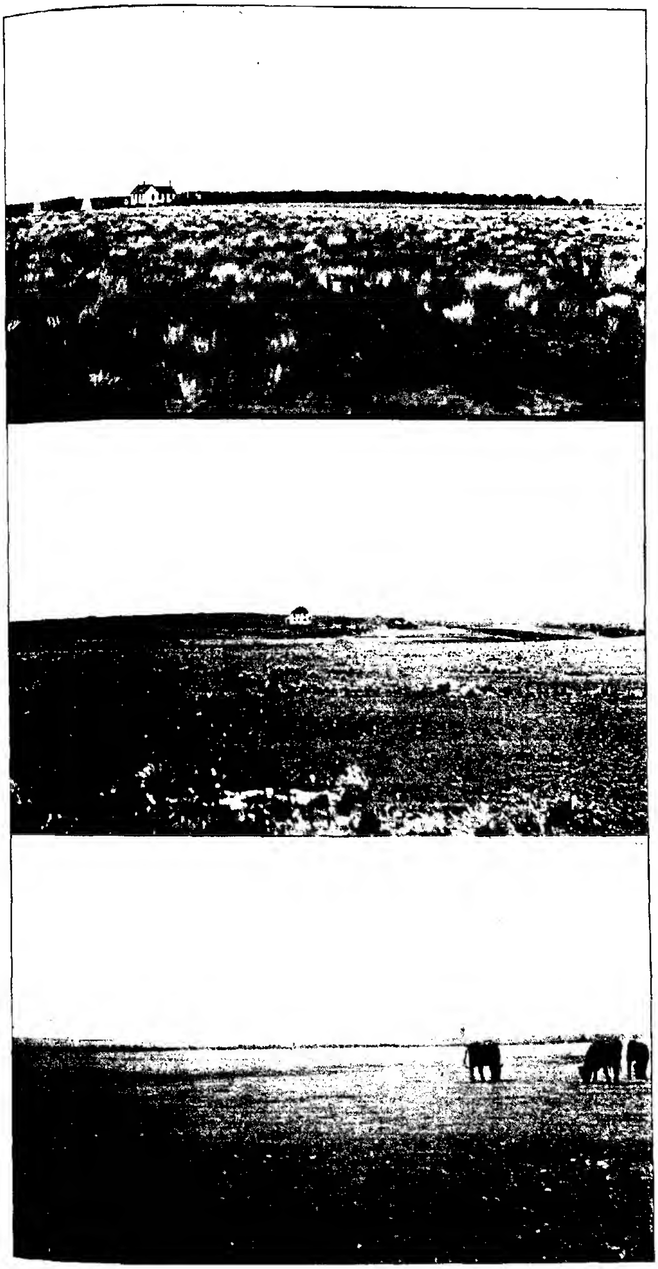
PLATE I.

Fig. 1.—Field II at Wauneta showing very level character of fields in this area. A young orchard is shown in the foreground.

Fig. 2.—Field III at McCook. Planted trees about the farmstead. Canyons in the loess at the right.

Fig. 3.—Field V at Holdredge, showing level topography. Planted trees in the distance.



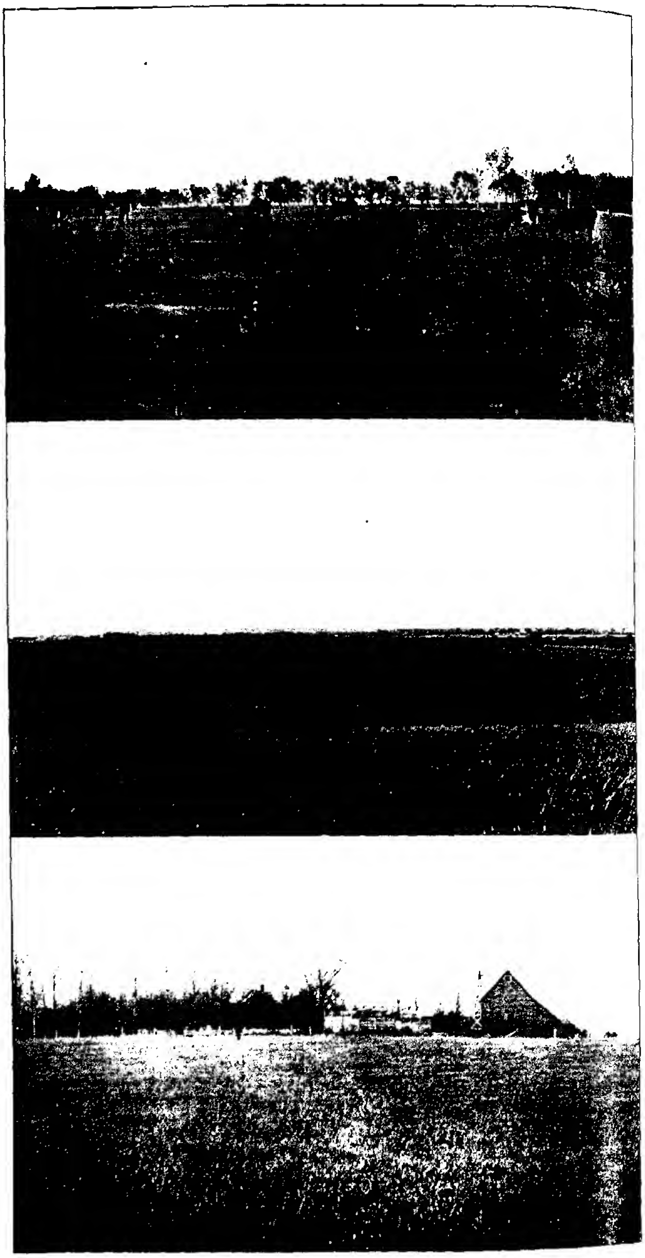


PLATE II.

Fig. 1.—Field IV at Hastings, showing very level topography. Planted trees in the distance.

Fig. 2.—Field IV at Lincoln, showing rolling topography and, in the distance, native trees along water-courses.

Fig. 3.—Field V at Weeping Water, showing orchard and shade trees about a farmstead. This was one of the very few comparatively level tracts that had not been brought under the plow.

PLATE III.

Fig. 1.—At the western edge of the loess plain. Looking westward from Field IV at Wauneta, showing the lower-lying plain of Tertiary rocks covered with residual soil. The loess extends about 300 yards beyond the immediate foreground.

Fig. 2.—A canyon in the loess between Fields II and IV at Wauneta, showing contact of loess with underlying unaltered Tertiary rock. The man is shown standing on a slight projection of the latter. The photograph was taken from the opposite side of the canyon.

THE LOESS SOILS OF THE NEBRASKA PORTION OF THE TRANSITION REGION:

II. HUMUS, HUMUS-NITROGEN AND COLOR.[1]

By

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INTRODUCTION.

In Nebraska the loess extends westward from the Missouri River for about 300 miles. Throughout this distance the temperature conditions are quite uniform, but there is a gradual decrease in the humidity of the climate, the normal annual precipitation, which exceeds 30 inches at the eastern boundary, steadily falling until it is less than 20 in the extreme western portion, while the rate of evaporation increases considerably. The climate of this region has been considered in detail in a previous paper (3).

The soil samples upon which the present article is based, were collected from 30 virgin prairie fields, 5 near each of six stations of the United States Weather Bureau shown in figure 1—Wauneta, McCook, Holdrege, Hastings, Lincoln and Weeping Water. In each field, at intervals of 30 feet, ten borings were made to a depth of six feet and composite samples prepared of each foot section, thus giving six samples from each field, the so-called "field samples." From these "area samples" were prepared by mixing equal weights of the corresponding 5 "field foot samples." Thus each of the "area samples" is a composite from 50 individual borings. In addition to this a set of 12 one inch samples was secured from the surface foot of each field, these being composites of 20 or 50 individual samples. The "area inch samples" are accordingly composites of 100 or 250 individual samples. The details of the method of sampling are given in the article above referred to.

[1] Received for publication February 10, 1916.

[2] The work reported in this paper was carried out at the Nebraska Agricultural Experiment Station, where the authors were Chemist and Assistant in Chemistry, respectively.

Humus.

"Humus" as used in this article refers to the *matière noire* of Grandeau (7, p. 148)—the portion of the soil soluble in 4 per cent ammonium hydroxide solution after previous treatment with 1 per cent hydrochloric acid. We have studied the distribution of this in the different foot levels, and by inch sections in the surface foot. In the first foot samples from all the fields we have determined the humus-nitrogen to see whether the proportion is distinctly higher in the semi-arid than in the humid soils. The constancy of the ratio of humus to the total nitrogen and to the organic carbon, and also the relation of the humus, the organic carbon and the total nitrogen to the soil color have been investigated.

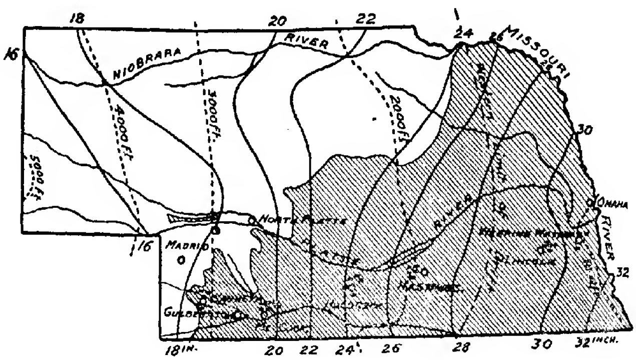

Figure 1—Map of Nebraska showing distribution of the loess (shaded), annual precipitation and location of fields sampled.

It is now generally recognized that a large number of the past determinations of humus, as this term is above defined, are unreliable because of the failure to recognize the influence of the relative amounts of the so-called "humus-ash" upon the accuracy of the determination (2, p. 322; 6, p. 56). As a high percentage of ash indicates an unreliable determination we report the amount of this wherever we employ data from gravimetric determinations.

Several reliable methods for the determination of humus are available. We compared that of Rather (12) with Hilgard (8, p. 246), and Moores-Hampton (11) methods and since it gave similar results, while requiring less time, adopted it in this study. In the case of the surface soils from the same locality it has been found that the intensity of the color of the ammonia extract is fairly closely concordant with the amount of humus contained (4). This permits of the use of a colori-

TABLE I.

HUMUS IN THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA, DETERMINED COLORIMETRICALLY.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
			WAUNETA.			
1	1.17	1.00	1.17	1.00	1.00	1.07
2	.87	.78	.87	.93	.74	.84
3	.74	1.08	.74	.93	.50	.80
4	.39	1.00	.70	.58	.34	.60
5	.26	.31	.87	.26	.20	.38
6	.18	.19	.82	.15	.17	.30
Average	.60	.73	.86	.64	.49	.66
			McCOOK.			
1	.93	1.48	1.17	1.08	1.00	1.13
2	.52	1.08	.61	.82	.40	.69
3	.39	1.04	.33	.45	.19	.48
4	.33	.82	.22	.24	.18	.36
5	.19	.30	.31	.19	.17	.23
6	.21	.19	.24	.16	.14	.19
Average	.43	.82	.48	.49	.35	.51
			HOLDREGE.			
1	1.48	1.65	1.75	2.00	2.15	1.81
2	.78	1.04	1.35	1.17	1.17	1.10
3	.37	.44	.66	.70	.39	.51
4	.22	.25	.44	.58	.24	.34
5	.16	.19	.22	.16	.15	.18
6	.13	.15	.20	.10	.13	.14
Average	.51	.62	.77	.78	.71	.68
			HASTINGS.			
1	1.40	1.67	1.26	1.55	1.55	1.49
2	.82	.92	.82	1.00	.82	.88
3	.42	.50	.40	.36	.28	.39
4	.26	.41	.17	.30	.15	.26
5	.23	.41	.14	.29	.13	.24
6	.13	.30	.10	.15	.12	.16
Average	.54	.70	.48	.61	.51	.56
			LINCOLN.			
1	2 55	2.55	2.15	2.33	2.33	2.38
2	.87	.64	.30	.56	.84	.64
3	.17	.13	.11	.23	.26	.18
4	.09	.08	.06	.12	.12	.09
5	.04	.05	.05	.09	.10	.07
6	.05	.07	.05	.06	.09	.06
Average	.63	.59	.45	.56	.62	.57
			WEEPING WATER.			
1	2.15	2.00	2.33	2.55	2.15	2.24
2	.70	.72	.72	1.40	.78	.86
3	.14	.10	.15	.14	.11	.13
4	.07	.08	.11	.10	.09	.09
5	.06	.06	.04	.08	.08	.06
6	.06	.05	.04	.04	.04	.05
Average	.53	.50	.56	.72	.54	.57

metric method, which is far more expeditious. In comparing humid and semi-arid subsoils we have found that the former may give an almost colorless and the latter a brown ammonia extract, while the amount of humus determined by the gravimetric method is practically the same in both. Even when the ammonia extract is almost colorless a gravimetric determination may show from 0.15 to 0.20 per cent humus with a humus ash equal to that in soils of high humus content. As a satisfactory method should indicate at least the relative amounts of the dissolved black substances we consider that the colorimetric method is altogether preferable for the subsoils, although the two methods appear about equally satisfactory for the surface soils.

TABLE II.

HUMUS IN THE FIRST AND SECOND FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA, DETERMINED GRAVIMETRICALLY.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
			WAUNETA.			
1	0.99	1.04	1.07	0.99	1.02	1.02
2	.65	.61	.72	.67	.64	.66
			McCOOK.			
1	1.12	1.27	1.15	1.15	1.04	1.15
2	.55	.81	.60	.67	.49	.62
			HOLDREGE.			
1	1.37	1.44	1.63	1.70	1.90	1.61
2	.69	.79	1.01	.95	.93	.87
			HASTINGS.			
1	1.50	1.67	1.39	1.56	1.42	1.51
2	.85	.92	.84	.91	.79	.86
			LINCOLN.			
1	2.30	2.22	2.19	2.27	2.34	2.26
2	1.08	.96	.80	.90	1.16	.98
			WEEPING WATER.			
1	2.13	2.09	2.24	2.43	2.28	2.23
2	1.18	1.30	1.08	1.65	1.27	1.29

While part of the samples have been subjected to only the gravimetric and part to only the colorimetric, both methods were used with the majority. As the surface soils, in general, give similar results by both we used only the gravimetric for the inch sections. Both methods were used with all the area foot samples and with the field samples from the first and second foot. The colorimetric method only was employed with

TABLE III.

"HUMUS ASH" FROM THE FIRST AND SECOND FOOT OF THE FIVE FIELDS OF EACH AREA.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
WAUNETA.						
1	.40	.33	.45	.34	.42	.39
2	.34	.27	.35	.32	.32	.32
McCOOK.						
1	.29	.32	.30	.29	.26	.29
2	.35	.27	.36	.31	.36	.33
HOLDREGE.						
1	.30	.29	.29	.34	.29	.30
2	.25	.23	.30	.28	.28	.27
HASTINGS.						
1	.24	.19	.20	.27	.23	.23
2	.27	.22	.27	.21	.22	.24
LINCOLN.						
1	.26	.38	.25	.22	.31	.28
2	.43	.18	.15	.19	.16	.22
WEEPING WATER.						
1	.29	.28	.36	.32	.37	.32
2	.16	.16	.14	.34	.18	.20

TABLE IV.

HUMUS IN THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg. Wtr. %	Average %
COLORIMETRIC DETERMINATION.							
1	1.07	1.13	1.81	1.49	2.38	2.24	1.69
2	.84	.69	1.10	.88	.64	.86	.83
3	.80	.48	.51	.39	.18	.13	.42
4	.60	.36	.34	.23	.09	.09	.29
5	.38	.23	.18	.22	.07	.06	.19
6	.30	.19	.14	.14	.06	.05	.15
Average	.66	.51	.68	.56	.57	.57	.59
GRAVIMETRIC DETERMINATION.							
1	1.02	1.15	1.61	1.51	2.26	2.24	1.63
2	.65	.62	.87	.86	.98	1.29	.88
3	.48	.35	.33	.35	.38	.55	.41
4	.34	.31	.29	.26	.26	.27	.29
5	.26	.27	.21	.28	.21	.23	.24
6	.26	.27	.18	.25	.15	.19	.22
Average	.50	.49	.58	.58	.71	.80	.61

the field foot samples from the lower levels. Thus we have data upon which to base a fair comparison of the two methods. We confirmed the earlier observations that with the colorimetric method better results are obtained when the standard used is a soil of the same type and from the same locality as the soils under investigation (4, p. 14).

TABLE V.

"HUMUS ASH" FROM THE AREA COMPOSITES.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
1	.39	.29	.30	.23	.28	.32
2	.32	.33	.27	.24	.22	.20
3	.37	.46	.34	.27	.19	.23
4	.45	.52	.37	.40	.25	.19
5	.53	.54	.37	.40	.24	.27
6	.60	.54	.39	.44	.34	.27

In Table I there is reported the humus content of the foot samples from the five fields in each of the six areas, as determined by the colorimetric method. As a standard we used the surface six inches of soil from one of the long cultivated fields on the experiment station farm. This contained 0.244 per cent nitrogen, 2.20 per cent humus and had a hygroscopic coefficient of 10.2.

In the case of all the field samples from the first and second foot the humus was determined by the gravimetric method also (Tables II and III). The same method was applied to the area composites of the lower four feet. In Tables IV and V the data for the area samples as obtained by the two methods are reported. Except in the case of the gravimetric determinations for depths below the second foot they are the averages for the field samples. Figure 2 shows graphically the distribution of humus as determined by the two methods. For the first foot samples the two methods give quite similar results and, as with the total nitrogen and the organic carbon (3, p. 226), the fields may be arranged in three groups, that highest in humus including those from Weeping Water and Lincoln, and that lowest those near Wauneta and McCook. For the second foot samples no such grouping is possible, and in the case of these the colorimetric method shows lower percentages than the gravimetric for all Weeping Water and Lincoln fields, while for those of the western four areas first the one method and then the other gives the higher results. For the levels below the second foot the colorimetric determinations show an increase in humus from east to west while the gravimetric show a quite uniform distribution. Considering the averages for the six feet the colorimetric determinations show no change from east to west, while the gravimetric indicate a distinct decrease.

Where, as in the present study, part of the determinations of humus have been made by the gravimetric method, and so represent the whole of the ammonia-soluble organic matter, and part by the colorimetric method and thus indicate merely the relative amounts of pigment, it is necessary, in order to avoid confusion, to indicate, wherever the term *humus* is employed, which method has been used. It might be preferable to continue to use this term to indicate simply the ammonia-soluble organic matter without regard to its color and to refer to values obtained by the colormetric method as *soluble pigment.* From the discussion in the following paragraphs it will be seen that this probably constitutes an indefinite portion of the organic matter and at most carries but a small portion of the soil nitrogen. Hence the percentages of soluble pigment as reported in the tables are to be regarded as indicating not the absolute, but only the relative, amounts present. Until the pigment has been isolated it will not be possible to secure a standard solution by means of which the actual percentages can be determined.

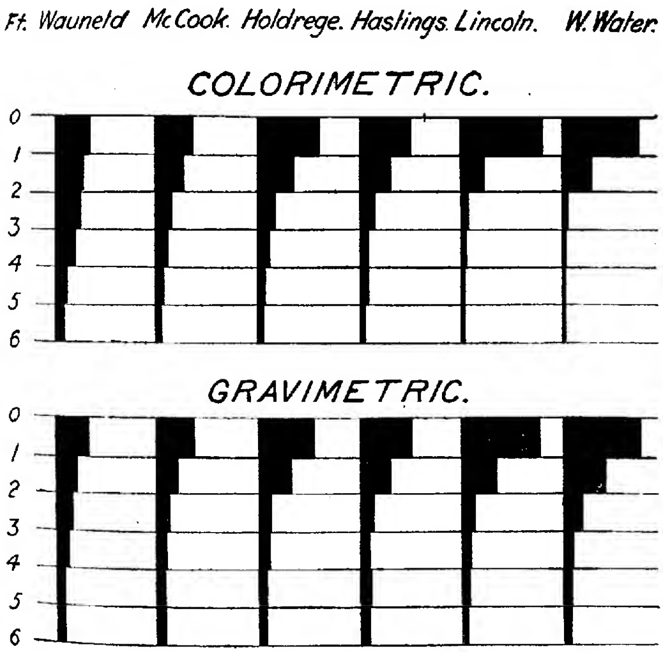

Figure 2—Diagram showing relative amounts of humus found by the two methods in the different areas.

When we employ the data from the colorimetric method we can sharply distinguish the fields of the most westerly, semi-arid two areas from the most easterly, humid two. The former are characterized by a content of soluble pigment lower in the surface foot but much higher in the third and lower foot sections (fig. 3).

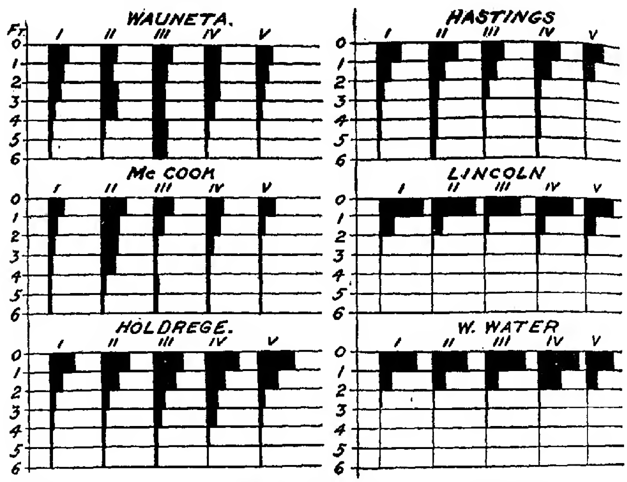

Figure 3—Diagram showing the distribution of humus, as determined colorimetrically, in the different fields.

In the western four areas, and at McCook and Wauneta especially, some of the fields show an exceptionally high content of soluble pigment at levels below the second foot. In Field II at McCook and II at Wauneta this continues through the fourth foot, and in III at Wauneta through the sixth. There is nothing found in the topography, drainage, etc. of these fields that offers any explanation of their exceptional composition. At the time the samples were taken we noticed the darker color of the subsoil, and later Field II at McCook was again visited and carefully examined to make sure that the samples were in color strictly representative of the lower levels. This exceptionally high content of soluble pigment in the deeper subsoil, 3 to 6 feet, exhibited by the three fields mentioned, while not an area characteristic, has been found only in the western areas. As all four western areas show a higher content at these depths than the eastern two it seems not improbable that whatever has caused the high content of soluble pigment in all the western fields has also been the cause of the exceptional amounts found in the three above mentioned.

From the data on the total nitrogen (3, p. 220), it will be seen that these exceptional amounts of soluble pigment are not accompanied by correspondingly high percentages of nitrogen, although the latter are above the average.

The humus in the area inch samples, determined gravimetrically, is reported in Table VI. It decreases from east to west and in all the areas decreases quite uniformly from the surface downward, the relative

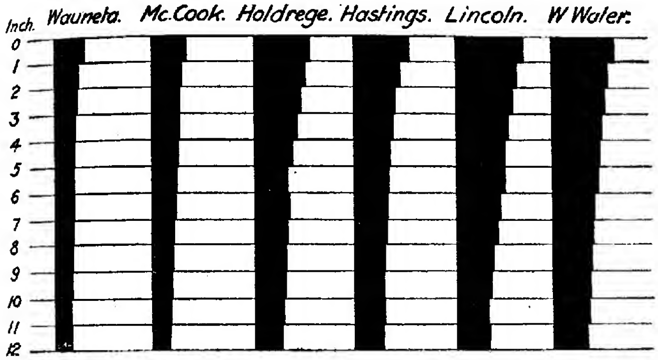

Figure 4—Diagram showing the distribution of humus in the surface foot.

change, inch by inch, being quite similar in all (fig. 4). The "humus ash" (Table VII) is highest in the surface inch, which may simply indicate that the ammonia solution dissolved more mineral matter from this section. If this ash were derived from phosphorus, potassium, etc., forming an essential part of definite organic compounds, it should be highest in the first inch samples from the eastern two areas, which is not the case. In these it amounts to less than one-fifth the humus, but in the McCook and Wauneta samples to more than one-half.

The Ratio of Humus to Nitrogen.

The total nitrogen and the organic carbon in all these samples has been previously reported (3, p. 226). The ratio of humus to nitrogen in the first and the second foot of all the fields, using the data from the gravimetric determinations, is reported in Table VIII. In the case of the surface foot the ratio averages slightly the highest in the eastern two areas, but for some of the fields in these it is lower than for certain fields in the intermediate two. All the fields in the western two areas show a lower ratio than those of the eastern two. The average for all the fields

for the second foot, 8.1, is similar to that for the first foot, 8.7. In all the fields of the eastern two areas the ratio is lower in the second than in the first foot, while in those of the other areas it is sometimes higher and sometimes lower.

TABLE VI.

HUMUS IN THE INCH SECTIONS OF THE SURFACE FOOT, DETERMINED GRAVIMETRICALLY.

Depth Inch	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	1.42	1.50	2.46	2.57	3.06	2.85	2.31
2	1.16	1.26	2.24	2.11	2.75	2.54	2.01
3	1.11	1.20	2.06	1.84	2.59	2.42	1.87
4	1.02	1.20	1.89	1.75	2.36	2.28	1.75
5	.98	1.12	1.65	1.58	2.17	2.17	1.61
6	.97	1.06	1.42	1.49	2.17	2.12	1.54
7	.97	1.01	1.50	1.48	1.97	1.94	1.48
8	.90	.94	1.38	1.44	1.89	1.88	1.41
9	.87	.87	1.36	1.33	1.65	1.79	1.31
10	.81	.85	1.32	1.30	1.58	1.77	1.27
11	.78	.79	1.27	1.33	1.45	1.68	1.22
12	.80	.76	1.19	1.25	1.47	1.56	1.17
Average	.98	1.05	1.65	1.62	2.10	2.10	1.58

TABLE VII.

"HUMUS ASH" FROM THE DIFFERENT INCH SECTIONS OF THE SURFACE FOOT.

Depth Inch	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	.96	.84	.77	.73	.47	.52	.71
2	.55	.43	.59	.50	.40	.40	.48
3	.42	.35	.35	.32	.40	.39	.37
4	.32	.32	.31	.36	.31	.29	.32
5	.31	.31	.30	.29	.35	.31	.31
6	.31	.30	.31	.23	.35	.34	.31
7	.31	.29	.30	.22	.33	.26	.29
8	.30	.29	.31	.27	.35	.27	.30
9	.33	.29	.30	.22	.27	.25	.28
10	.35	.29	.29	.29	.27	.28	.29
11	.31	.29	.30	.25	.26	.23	.27
12	.31	.29	.29	.22	.30	.24	.28
Average	.40	.36	.37	.33	.34	.32	.35

The substitution of the data from the colorimetric determination (Table IX) affects the ratios very much less in the case of the first two feet than in that of the lower sections. For the latter the resulting ratios at Lincoln and Weeping Water are in most cases less than 2, while those for the more westerly areas are in general far above this, values of 12 or even higher being found. Thus it is evident that the amount of the dark colored, ammonia-soluble matter shows no definite relation to the total

nitrogen content, a condition which would indicate that the substance or substances causing the black or brown color of the ammonia extract contain at most but a very small proportion of the total nitrogen of the soil.

In the inch sections of the surface foot the ratio of humus, as determined gravimetrically, to nitrogen (Table X), is somewhat lower in the western two areas, averaging between 7 and 8, while in the other four the average is approximately 9.

TABLE VIII.

RATIO OF HUMUS, AS DETERMINED GRAVIMETRICALLY, TO NITROGEN IN THE FIRST TWO FEET OF EACH OF THE FIELDS.

FIRST FOOT.

Field No.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.
I	7.3	7.8	8.0	8.8	9.5	9.3
II	7.5	8.7	8.3	9.6	9.1	9.0
III	7.4	8.3	9.9	7.6	9.4	9.2
IV	7.7	8.0	9.0	9.2	9.5	10.0
V	7.7	8.3	9.1	8.2	9.7	9.2
Average	7.5	8.3	8.9	8.6	9.4	9.5

SECOND FOOT.

Field No.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.
I	8.1	7.0	7.7	8.9	8.8	7.9
II	7.8	9.0	8.1	9.7	6.6	8.7
III	7.8	7.5	9.1	8.2	6.4	7.4
IV	8.2	7.6	9.1	9.8	7.6	9.6
V	8.1	5.8	9.0	7.6	8.7	8.3
Average	7.9	7.4	8.6	8.8	7.6	8.4

Organic Carbon-Humus Ratio.

The ratio of organic carbon to humus in the inch sections of the surface foot is shown in Table XI. It averages slightly the highest in the western areas. In each of the six areas it is highest in the surface inch. In the lowest sections it is alike in the most westerly and the most easterly areas. The average for all the sections in all the areas is 1.4. Accordingly the ratio of organic matter (C $\times$ 1.7241) to humus will be 1:2.4; in other words about 40 per cent of the organic matter of the surface foot is soluble in a 4 per cent ammonia solution.

In the area foot samples (Table XII) the ratio of organic carbon to humus, as determined by the gravimetric method, is fairly constant in the first two feet, rising slightly from east to west in the first, as already shown in the series of inch sections. For the lower foot sections while the average is the same as for the first two feet the ratio varies from 0.7 to 1.8. Using the colorimetric determinations the ratio in the third, fourth, fifth and sixth foot varies from *ca.* 1.0 to 1.5 in the western four areas, and from *ca.* 3.5 to 6.0 in eastern two (Table XII).

TABLE IX.

RATIO OF HUMUS, DETERMINED COLORIMETRICALLY, TO NITROGEN.

WAUNETA.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	8.1	7.3	8.1	7.7	7.6	7.8
2	10.9	10.0	9.5	11.3	9.4	10.2
3	12.5	18.6	10.3	11.9	8.3	12.3
4	9.1	17.9	16.7	12.3	7.9	12.8
5	7.9	8.9	17.8	6.7	5.6	9.4
6	6.4	7.6	16.7	6.5	6.3	8.7

McCOOK.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	6.5	10.1	8.5	7.5	8.0	8.1
2	6.6	12.0	7.6	9.3	4.4	8.0
3	9.1	15.5	6.3	8.6	3.9	8.7
4	9.2	16.7	5.9	6.7	5.3	8.8
5	6.1	8.1	9.1	6.5	5.4	7.0
6	6.2	6.3	8.0	5.5	5.2	6.2

HOLDREGE.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	8.6	9.5	10.4	10.6	10.3	9.9
2	8.8	10.6	12.0	11.2	11.3	10.8
3	6.7	6.9	8.9	9.3	7.1	8.0
4	6.1	5.8	8.3	10.4	6.5	7.2
5	5.2	5.0	5.5	5.0	5.6	5.3
6	3.8	4.4	5.1	2.9	4.6	4.2

HASTINGS.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	8.2	9.6	6.9	9.2	8.9	8.6
2	8.6	9.7	8.0	10.8	7.9	9.0
3	7.1	9 4	6.4	6.7	4.7	6.9
4	6.0	10.5	3.9	9.4	3.3	6.6
5	5.3	14.1	3.4	11.6	3.2	7.5
6	4.5	11.1	3.0	6.2	3.5	5.7

LINCOLN.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	10.6	10.4	9.2	9.8	9.6	9.9
2	7.1	4.4	2.4	4.6	6.3	5.0
3	2.5	1.8	1.5	3.6	3.6	2.6
4	1.8	1.3	1.0	1.9	1.8	1.6
5	.9	1.1	1.2	2.2	2.8	1.6
6	.9	1.5	1.2	1.5	2.5	1.5

WEEPING WATER.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	9.4	8.7	9.6	10.5	9.1	9.5
2	4.7	4.8	4.9	8.2	5.1	5.6
3	1.7	1.2	1.9	1.4	1.6	1.6
4	1.3	1.5	2.1	1.4	1.4	1.5
5	1.3	1.4	1.0	1.8	1.9	1.5
6	1.5	1.3	1.1	1.0	1.0	1.2

TABLE X.

RATIO OF HUMUS, AS DETERMINED GRAVIMETRICALLY, TO NITROGEN IN THE INCH SECTIONS OF THE SURFACE FOOT.

Depth In.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	7.1	7.4	7.6	7.3	9.0	8.4	7.8
2	6.7	7.6	8.4	8.9	9.5	8.6	8.3
3	6.7	7.3	8.8	8.9	10.0	9.3	8.5
4	6.8	7.5	9.2	9.4	9.6	8.3	8.5
5	7.3	7.7	8.8	9.0	9.3	9.3	8.6
6	7.6	7.6	8.4	9.2	9.7	9.4	8.6
7	8.2	7.9	9.6	9.5	9.4	8.9	8.9
8	8.0	8.0	9.5	9.6	9.4	9.0	8.9
9	7.7	7.9	9.6	9.2	8.5	8.7	8.6
10	7.8	8.3	9.7	9.3	8.7	8.9	8.8
11	8.0	8.2	9.5	9.7	8.4	8.8	8.8
12	8.4	8.3	9.4	9.5	9.0	8.4	8.8
Average	7.5	7.8	9.0	9.1	9.2	9.1	8.7

TABLE XI.

RATIO OF ORGANIC CARBON TO HUMUS, AS DETERMINED GRAVIMETRICALLY, IN THE DIFFERENT INCH SECTIONS OF THE SURFACE FOOT OF THE SIX DIFFERENT AREAS.

Depth In.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	2.0	1.6	1.9	1.8	1.5	1.6	1.7
2	1.8	1.5	1.6	1.5	1.3	1.5	1.5
3	1.7	1.6	1.4	1.4	1.3	1.3	1.4
4	1.6	1.5	1.3	1.3	1.3	1.3	1.4
5	1.5	1.5	1.3	1.3	1.3	1.3	1.4
6	1.5	1.5	1.4	1.2	1.3	1.3	1.3
7	1.4	1.4	1.2	1.2	1.3	1.2	1.4
8	1.4	1.4	1.2	1.2	1.3	1.2	1.3
9	1.4	1.5	1.2	1.2	1.4	1.3	1.3
10	1.4	1.4	1.2	1.2	1.3	1.3	1.3
11	1.3	1.4	1.2	1.1	1.4	1.3	1.3
12	1.3	1.3	1.2	1.2	1.3	1.3	1.3
Average	1.5	1.5	1.3	1.3	1.3	1.3	1.4

As the total organic matter in the lower levels is quite similar in all the areas, as is also the ammonia soluble portion—the humus as determined gravimetrically—the change from east to west is apparently confined chiefly to the amount of pigment, which forms a quite unknown proportion of the dissolved organic matter.

Percentage of Nitrogen in the Humus.

For the extraction of the humus-nitrogen 10 gm. of dry soil was placed in a glass-stoppered flask and treated with 500 c.c. 4 per cent potassium hydroxide solution. The mixture was shaken at frequent intervals for 8 days, after which it was allowed to stand over night that the suspended soil particles might settle. An aliquot of this dark colored ex-

tract was used for the Kjeldahl determination. This method (1) is much more convenient and expeditious than that of Hilgard (8, p. 247), while extracting as large a proportion of the soil nitrogen.

TABLE XII.

RATIO OF ORGANIC CARBON TO HUMUS IN THE FOOT SECTIONS.

A.—HUMUS DETERMINED BY COLORIMETRIC METHOD.

Depth Ft.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	1.5	1.5	1.2	1.4	1.2	1.3	1.3
2	.9	1.2	1.0	1.2	2.7	2.0	1.5
3	.8	1.2	1.2	1.5	3.7	6.1	2.4
4	.8	.9	1.1	1.5	3.9	5.3	2.2
5	.8	1.2	1.3	1.1	3.6	4.3	2.1
6	.9	1.1	1.5	1.3	3.8	4.2	2.1
B.—HUMUS DETERMINED BY GRAVIMETRIC METHOD.							
1	1.6	1.6	1.4	1.4	1.3	1.3	1.4
2	1.2	1.3	1.2	1.2	1.3	1.4	1.3
3	1.3	1.6	1.8	1.6	1.7	1.4	1.6
4	1.4	1.1	1.3	1.3	1.3	1.8	1.4
5	1.2	1.1	1.1	.9	1.2	1.1	1.1
6	1.0	.8	1.2	.7	1.5	1.1	1.0

The percentage of nitrogen in the humus, based upon the gravimetric determinations of the latter, in the surface foot of each field, is reported in Table XIII. It averages lower for the eastern two than for the other areas, but the differences are so small, being no greater than the variations within the different areas, that the data justify little hope of finding in the semi-arid region soils with humus showing an abnormally high content of nitrogen. Recent work has rendered it probable that even the arid soils as a rule are not characterized by a high content of nitrogen in the humus (1).

TABLE XIII.

PERCENTAGE OF NITROGEN IN THE HUMUS FROM THE FIRST FOOT OF THE DIFFERENT FIELDS.

Field No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	8.3	8.0	7.6	8.4	6.6	6.9
II	8.0	7.2	7.5	7.5	6.5	7.3
III	8.0	7.4	6.8	8.0	6.6	7.4
IV	7.8	7.5	7.0	8.4	6.5	6.5
V	7.7	7.5	6.5	7.6	6.7	6.5
Average	8.0	7.5	7.1	8.0	6.6	6.9

Color of the Soils.

Comparisons of the color of the 180 foot-samples, both in an air-dry and in a moist condition, were made. For this purpose 25 gm. samples were placed in small porcelain dishes and then arranged in order of color with the darkest sample in the group at one end and the lightest-colored in that at the other. After various trials the final comparisons were made after moistening the soils by the addition to each of 10 c.c. water, covering the dish to prevent evaporation, allowing it to stand over night and making the comparison on the following day. As it was thought that the results would be more satisfactory if the soils were all brought into a definite moisture relation to their maximum water-holding capacity, as shown in the field, a number of the samples were placed in contact with a large mass of soil at its hygroscopic coefficient, treated with 50 per cent of their weight of water and allowed to stand, protected from evaporation, until water had practically ceased to be lost from them. As this method gave results no more promising than those obtained in the more expeditious manner described above, general use of the former was not made. We were able to distinguish only eight shades of color. The ranking of each sample is indicated in Table XIV. Thus that given "1" belongs to the darkest colored group, and that given "8" to the lightest. When only samples from the same area or from similar areas were compared the results obtained were fairly satisfactory, there being no difficulty in deciding which was the darker of two, if they were at all distinguishable. Thus the Wauneta and McCook samples were directly comparable, and these could, although less satisfactorily, be compared with those from Holdrege and Hastings; but the Weeping Water and Lincoln subsoils samples, while comparable with one another, could not be satisfactorily compared with the subsoils from the other areas. The difficulty is to be attributed to coloring matters other than humus, the high content of calcium carbonate in the western soils and the large amount of ferric oxide in the eastern affecting the shade produced by the ammonia-soluble black substances.

It will be seen that in general the colors bear somewhat the same relation to one another as the percentages of humus determined colorimetrically, but not as those obtained by the gravimetric method. The depth of color of a soil or subsoil is a fairly satisfactory index as to the relative amount of ammonia-soluble dark-colored organic matter present, provided other coloring matters do not occur in sufficient amounts to affect it, but as this pigment in the subsoil bears no definite relation to either the total nitrogen or the organic carbon, the color of the subsoils does not serve as a reliable index of the relative amounts of either of these constituents.

TABLE XIV.

THE RELATIVE SHADE OF COLOR OF THE SAMPLES FROM THE DIFFERENT FIELDS. 1 INDICATES THE DARKEST AND 8 THE LIGHTEST COLORED.

WAUNETA.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	2	2	2	2	2	2
2	3	3	2	2	3	3
3	4	2	3	3	5	3
4	6	3	4	5	7	5
5	7	6	4	6	7	6
6	8	7	4	7	8	7

McCOOK.

1	3	2	2	2	2	2
2	4	3	4	3	6	4
3	8	4	7	6	7	6
4	8	5	8	8	7	7
5	8	7	7	8	8	8
6	8	7	8	8	8	8

HOLDREGE.

1	1	1	1	1	1	1
2	2	3	3	3	3	3
3	5	5	5	5	5	5
4	8	8	6	8	6	7
5	8	8	8	8	8	8
6	8	8	8	8	8	8

HASTINGS.

1	1	1	1	1	1	1
2	3	3	4	3	3	3
3	6	6	6	5	6	6
4	6	8	8	8	8	8
5	8	8	8	8	8	8
6	8	8	8	8	8	8

LINCOLN.

1	1	1	1	1	1	1
2	2	4	5	4	2	3
3	6	8	8	6	6	7
4	8	8	8	8	8	8
5	8	8	8	8	8	8
6	8	8	8	8	8	8

WEEPING WATER.

1	1	1	1	1	1	1
2	4	4	4	3	4	4
3	8	8	8	6	8	8
4	8	8	8	8	8	8
5	8	8	8	8	8	8
6	8	8	8	8	8	8

As after complete extraction with ammonium or alkaline hydroxide the residue from the surface soil more closely resembles that from the subsoil, the original difference in color is to be attributed largely to the soluble pigment. The formation of this, which is probably a product of bacterial action, is favored to a much greater depth in the drier, better aerated subsoils of the western areas (fig. 3), which would suggest that it is produced by aerobic organisms.

COMPARISON WITH CHERNOZEM SOILS.

The thickness of the dark surface layer of the typical Russian Chernozem soils, acording to Kossowitch (9, p. 284), is usually between 28 and 40 inches, in some places exceeding 60 and in others falling below 16, about half of this being occupied by the upper uniformly colored darker portion, the lower half passing irregularly into the light colored subsoil. While the soils of the Nebraska portion of the Transition Region show a uniformly colored upper portion and a lower portion gradually shading off into the lighter colored subsoil, the former, even in the most easterly areas, would appear to be lighter colored and shallower than the typical Chernozem, and in the western areas the soils seem to resemble more closely the Russian chestnut, or chocolate-colored soils found near the drier borders of the Chernozem zone. We find a great thickness of the dark layer only in the valleys, where it frequently extends to 3 and occasionally to 9 feet.

In the loess of the transition region we have found no dark-colored layer in the subsoil at some distance from the surface, such as is frequently found in the Russian Chernozem and there regarded as the remains of a former surface soil buried by a later deposition of loess. Near Madrid, not far from the western border of the loess in Nebraska, but on residual soil, we have found the dark soil uniform in color to a depth of seven feet, it occurring on the northeast slopes of hills as though formed by the southwest winds steadily depositing dust among the prairie plants.

Another common feature of the Chernozem, the uniformly dark-colored tongues and veins extending downward from the surface layer, seems to be entirely absent from these loess soils. In other studies one of us has encountered these in typical development in the heavier soils of the Red River Valley, as around Winnipeg. They also are found near Indian Head in Saskatchewan (5).

Data on the ***matière noire*** content of Russian soil are not available, the ***humus*** reported by Russian investigators being the same as our "organic matter of the soil," determined by combustion.

Comparison with Arid Soils.

It is of interest to compare the humus content of the semi-arid soils from the most westerly two areas with that of the arid soils of the regions of winter rains. Loughridge (10) has recently reported the humus in a large number of columns of California soils, most of these being taken to a depth of 12 feet and the humus determined by the Hilgard method. In general the humus is low in the surface foot and decreases gradually downward. Neither in amount nor in distribution does it appear to differ markedly from that in the semi-arid areas of this study. Table XV shows the similarity. We have no data showing to what extent the subsoils resemble one another in color, but the surface soils of the semi-arid areas are much darker in color than those of the California valleys.

TABLE XV.

COMPARISON OF AMOUNT OF HUMUS IN THE SEMI-ARID TRANSITION SOILS WITH THAT IN THE ARID CALIFORNIA SOILS REPORTED BY LOUGHRIDGE. THE HUMUS IN BOTH CASES WAS DETERMINED GRAVIMETRICALLY.

Depth Foot	Wauneta Av. 5 Fields %	McCook Av. 5 Fields %	Sacramento Valley Av. 18 Columns %	San Joaquin Valley Av. 23 Columns %
1	1.02	1.15	1.04	.80
2	.65	.62	.75	.51
3	.48	.35	.58	.37
4	.34	.31	.45	.25
5	.26	.27	.36	.23
6	.26	.27	.32	.17
Average	’50	.49	.58	.39

Summary.

The loess soils studied represent six one-foot sections from the surface downward, and the twelve one-inch sections of the surface foot, from five virgin prairie fields in each of six so-called "areas" in Nebraska, located between the Missouri River and the western limit of the loess, a distance of more than 300 miles, in which, while the temperature conditions, wind velocity, and relative humidity of the air are quite uniform there is a great range in the aridity, the mean annual precipitation decreasing from more than 30 inches in the east to less than 20 in the west, while the rate of evaporation from a free water surface during the six months, April to September, increases from 36 to 45 inches.

The gravimetric method for the determination of humus *(matière noire)* was found in the case of the subsoils to fail to indicate the relative amounts of ammonia-soluble, dark-colored organic matter present. A colorimetric method is preferable for the subsoils; in the case of the surface soils it is at least fairly satisfactory for the determination of the whole of the ammonia-soluble organic matter.

Within the surface foot the humus decreases from the first to the twelfth inch and from east to west. The rate of decrease downward is independent of the degree of aridity. In the second foot the decrease from east to west is less marked than in the first, while in the still lower levels the humus as determined gravimetrically, shows no distinct change from east to west.

No marked differences in the percentage of nitrogen in the humus was to be found between the soils from the most humid and those from the most arid parts of the region.

The soluble pigment in the surface foot was found to decrease in passing from east to west while that in the third to sixth foot increases. A relatively low amount in the surface foot with a relatively high content in the subsoil characterizes the soils from the more arid portion of the region.

The colors of the soil and subsoils agree in general with the amounts of soluble pigment found by the colorimetric method. Comparisons of the color were difficult in the case of the subsoils on account of the presence of varying amounts of coloring matters other than the soluble pigment, which causes the difference in color between surface soil and subsoil.

The color of the subsoil,like its content of soluble pigment, does not serve as an index of either the total nitrogen, the organic carbon or the amonnia-soluble organic matter present.

The color of the soils in the western areas is lighter, and in all the areas the dark-colored surface layer is shallower, than in the typical Russian Chernozem. Buried soil surfaces as well as the dark tongues and veins, common in the Russian Chernozem, appear to be absent in the loess of the Nebraska portion of the Transition Region.

Gravimetric determinations show the humus of the soils of the western semi-arid areas to be similar in amount and in distribution to that of typical arid California soils.

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CAN SOIL BE STERILIZED WITHOUT RADICAL ALTERATION?[1]

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The widespread adoption of soil as a culture medium in preference to solutions in the study of soil biology problems involves a fundamental difficulty, which merits more attention than is at present being bestowed upon it. In a word, the sterilization of soil, whether by heat or antiseptics, induces certain profound changes in the chemical and physical constitution of the soil. Since the guiding motive in the use of soil as a culture medium is to obtain results which may be correlated more closely with actual field conditions, that purpose is in a measure defeated, so long as the methods of sterlization, as commonly practiced, are drastic in their effects. A review of the literature (4) failing to offer any adequate solution, a preliminary investigation was undertaken in an effort to devise some method whereby the soil might be rendered sterile with a minimum amount of alteration. Experimentation was conducted along the following lines: 1. The intermittent sterilization of soil by dry heat; 2. The relative sterilizing efficiency of various chemical substances used as soil antiseptics; 3. Volatile antiseptics applied in partial vacuum; and 4. Volatile antiseptics applied under pressure at 80° C.

The Intermittent Sterilization of Soil by Dry Heat.

It has been pointed out by Russell and Hutchinson (11, 12), Pickering (8, 9), Schreiner (13), Seaver and Clark (14), and others, that heating the soil causes a distinct change in its chemical composition. Various temperatures from 60° to 170° C. have been employed with the inevitable result of an alteration in the constitution of the soil. Pickering (9) states, however, that heating at 82° C. does not cause a much greater production of toxins than heating at 50° or 60° C., consequently it was deemed advisable to use this temperature in an attempt to sterilize the soil completely. From the work of Russell and Hutchinson (11, 12), as well as that of Cunningham and Löhnis (2), it seemed valid to conclude that this degree of heat would be sufficient to kill all the living protozoa and most of the bacteria. Likewise, the cysts of protozoa were killed at 72° C. in solutions (which would represent about 60° to 65° C. in the soil). Moist heat is known to be more efficient in its destructive action than dry heat, but the laboratory facilities did not permit the use of the former.

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In view of the fact that the spores of bacteria or fungi might resist 82° C., it seemed desirable to follow a well-known bacteriological procedure and sterilize intermittently for a number of days at the same temperature. In this way the spores present would have ample opportunity to germinate, and the living forms would immediately succumb to the temperature which the spores might have been able to resist. Likewise, by this method the production of toxins, and the alteration of the chemical composition of the soil was reduced to a minimum, while the biological factors suffered decimation.

A point of considerable importance which had been attacked by Richter (10) and Koch (3), namely, the difference in the effect of sterilization upon air-dry and moist soil, was included in this investigation.

The method of procedure was as follows, using Penn Clay Loam soil, a chemical analysis of which is given in Table I. Because of the fact that it is more difficult to sterilize a heavier than a lighter soil, the results obtained by using Penn Clay Loam would thus be more exacting, than if a sandier soil were employed.

TABLE I.

CHEMICAL ANALYSIS OF PENN CLAY LOAM.

(HCL sp. gr. 1.115)

	Per Cent		Per Cent
Insoluble Matter	78.2820	P_2O_5	.1282
K_2O	.5496	SO_3	.0497
Na_2O	.1790	Volatile Matter	8.9200
CaO	.3962	Total Nitrogen	.1722
MgO	.9041	Total Phosphoric Acid	.1340
Fe_2O_3	4.1900	Total Potash	2.1700
Al_2O_3	6.3168	Total Carbon	2.4500

Fifty-gram portions of soil were placed in cotton-plugged 200 c.c. Erlenmeyer flasks. One series of ten flasks containing air-dry soil (having 4.5 per cent water), the other series of ten flasks containing 25 per cent of water (calculated on the water-free basis), which was equivalent to 60 per cent of the moisture-holding capacity of the soil.

Both series of flasks were incubated at 22° C. for 24 hours to allow excystation of protozoa in moist soil and to ensure the presence of vegetative forms of bacteria. (It might be noted, however, that a three-day incubation would have been preferable.) The flasks were then placed in a hot-air oven and heated until the constant temperature of the soil registered 82° C. for one hour. After this treatment all the flasks were again placed in the incubator at 22° C. for 24 hours, and two flasks of each series were taken for bacterial counts on Lipman and Brown's (5) "synthetic" agar. The counts were made in triplicate. The plates were counted after 3 days had elapsed.

The process outlined above was repeated for 5 successive days, two flasks of each series being removed each day and bacterial counts made on the results of each day's heating. On the last day, the soil was incubated for 48 hours instead of 24 to make doubly certain of having all the biological forms in the soil in the active living state. Also the plates were incubated for 7 instead of 3 days.

TABLE II.

INTERMITTENT STERILIZATION BY DRY HEAT AT 82° C.

MOIST SOIL (PENN CLAY LOAM) 25% H_2O.

Treatment	Bacterial Count Millions per gm. Soil		Total Water-Soluble Solids in gm.		Organic Solids in gm.		Inorganic Solids in gm.	
	Dup.	Av.	Dup.	Av.	Dup.	Av.	Dup.	Av.
	48.000		.0216		.0108		.0108	
Check	47.500	47.750	.0224	.0220	.0132	.0120	.0092	.0100
	12.300		.0304		.0164		.0140	
After 1st Day's Heating	12.400	12.350	.0316	.0310	.0180	.0172	.0136	.0138
	0.711		.0320		.0176		.0144	
After 2nd Day's Heating	0.632	0.672	.0316	.0318	.0172	.0174	.0144	.0144
	0.075		.0282		.0118		.0164	
After 3rd Day's Heating	0.067	0.071	.0296	.0289	.0184	.0151	.0112	.0138
	0.037		.0310		.0170		.0140	
After 4th Day's Heating	0.046	0.042	.0325	.0318	.0170	.0176	.0145	.0143
	0.001		.0322		.0173		.0149	
After 5th Day's Heating	0.002	0.005	.0320	.0321	.0167	.0170	.0153	.0151

AIR-DRY SOIL (PENN CLAY LOAM) 4.5% H_2O.

Treatment	Dup.	Av.	Dup.	Av.	Dup.	Av.	Dup.	Av.
	45.000		.0216		.0108		.0108	
Check	42.000	43.050	.0224	.0220	.0132	.0120	.0092	.0100
	52.500		.0200		.0164		.0036	
After 1st Day's Heating	50.200	51.350	.0212	.0206	.0164	.0164	—.0048	—.0042
	11.300		.0332		.0176		.0166	
After 2nd Day's Heating	11.800	11.500	.0320	.0326	.0164	.0170	—.0156	—.0161
	9.250		.0260		.0172		.0084	
After 3rd Day's Heating	9.660	9.400	.0270	.0265	.0180	.0176	—.0092	—.0088
	3.525		.0237		.0121		.0116	
After 4th Day's Heating	4.400	3.962	—.0220	—.0229	.0112	.0116	—.0108	—.0112
	3.424		.0228		.0075		.0153	
After 5th Day's Heating	3.500	3.462	.0271	.0250	.0122	.0093	.0149	.0151
Moist heat at 120° C. for			.1810		.0900		.0795	
15 min. at 15 lbs. pres're	Sterile		.1800	.1805	.1005	.0953	.0910	.0853

Treatment in Moist Soil (25 % H_2O)	Ammonia Release Average in grams
Check	.0014
After 1st Day's Heating..............................	.0021
After 2nd Day's Heating..............................	.0019
After 3rd Day's Heating..............................	.0019
After 4th Day's Heating..............................	.0019
After 5th Day's Heating..............................	.0019

The results are recorded in Table II. All the protozoa were killed after the initial treatment by heating to 82° C. for one hour. Löhnis' (2) soil extract was employed as a medium for determining the presence of protozoa, 100 c.c. being inoculated with 50 gm. of soil, and a microscopical examination made for 5 successive days. Fungi, however, persisted throughout the experiment; species of Penicillium and Mucor being recognized.

An examination of the results of the bacterial counts represented in figure 1 reveals the fact that in moist soil the numbers of bacteria decrease successively, in a remarkable manner from 47,750,000 per gram on the first day to 1,500 on the last day. On the other hand, however, there is an initial depression of bacterial numbers exhibited in the air-dry soil, followed by a gradual decrease in the numbers of bacteria on the subsequent days, which is substantially less effective than the decrease operating in the moist soil. A variation is noted in the bacterial counts on air-dry soil on the second day, for instead of a decrease there is an increase which may be ascribed to the immediate utilization of some nutrients becoming more available by the first day's heating.

It may be observed, parenthetically, that the soil was incubated for 48 hours instead of 24 on the last day, thus enabling the bacteria to multiply to a considerable extent after removal from the sterilizer and magnifying the bacterial count accordingly. Consequently, the number recorded is not a fair index of the actual number of bacteria present in the soil immediately after heating, but represents an addition over and above that amount.

Further, the plates were incubated for 7 days instead of 3 days for the purpose of ascertaining whether the number of colonies increased to any appreciable extent after 3 days. A negligible increase was noted.

Therefore, it is evident from the above results, that the intermittent sterilization of moist soil by dry heat is decidedly more efficacious in reducing the bacterial numbers than the same treatment with air-dry soil.

For the purpose of determining the amount of increase of the water-soluble constituents of the soil as a result of intermittent sterilization by dry heat, the following method was employed.

Fifty grams of the same kind of soil were heated under the same conditions as previously and then vigorously shaken with distilled water until the leachings made up a volume of 200 c.c. An aliquot portion of 50 c.c. was evaporated to dryness on a water-bath, dried in a hot-air oven at 108° C. for one hour (according to the method described by Seaver and Clark) (5), weighed, ignited, and then weighed again. The first weight represents the total solids, the final weight represents the inorganic constituents, and the difference between the two weights represents the organic constituents.

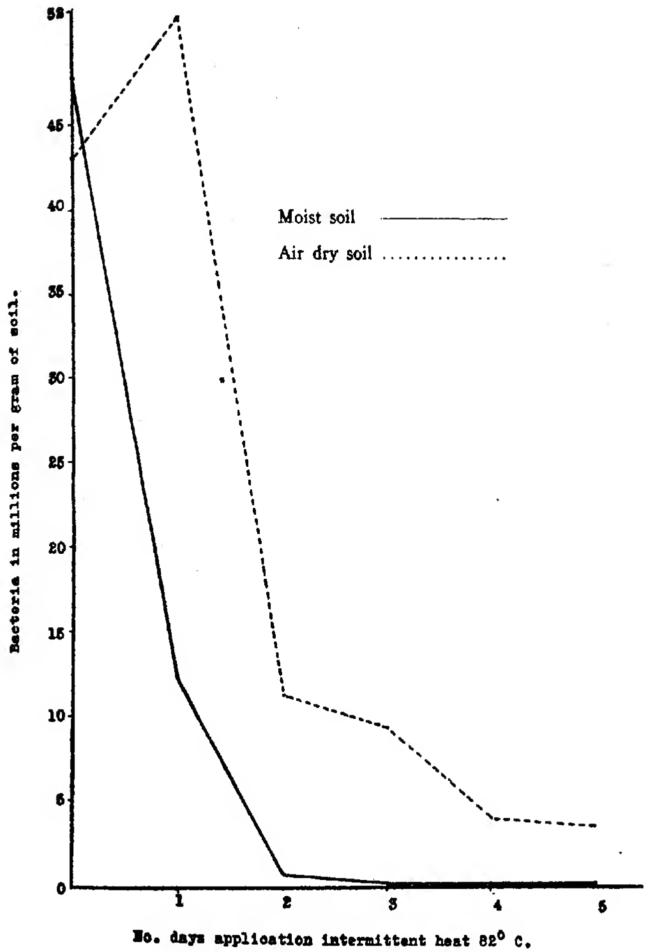

Fig. 1. Diagram showing the effect of intermittent heat for 5 days at 82° C. upon the numbers of bacteria in moist soil and in air-dry soil.

It is seen from Table II that sterilization under these conditions increases the amount of total solids 45.91 per cent; and that after the initial heating the amount of total-solids does not increase within experimental error.

It is interesting to note the comparison between the increase in the amount of water-soluble solids as a result of intermittently dry heat at 82° C. and the increase due to subjecting the soil to steam at 120° C. under 15 pounds pressure for 15 minutes, which is the usual laboratory method employed in soil biology investigations. The latter method is responsible for almost sixteen times the amount liberated by subjection to intermittent dry heat. The ammonia released by the sterilizing treatment at 82° C. is greatest after the first day and remains practically constant thereafter.

Considerable variation is noted in the amount of total solids in the air-dry soil, and this discrepancy may be accounted for by the fact that the heat was not able to permeate uniformly throughout the soil in a dry state.

In summarizing the foregoing results, the following points are to be noted:

1. Intermittent partial sterilization at 82° C. kills the greater portion of the bacterial population, as indicated by growth on Lipman and Brown's synthetic agar.
2. The treatment kills all the protozoa in the soil, as indicated by their non-appearance in Löhnis' soil extract medium.
3. Fungi persist throughout the experiment, as indicated by their presence on the culture media.
4. The sterilization treatment increases the total solids in the soil about 46 per cent, thereby altering the chemical composition of the soil and changing it as a medium for biological activity, but only one-sixteenth as much as by the common method of steam sterilization.
5. Where the time-element is of considerable importance the above method is undesirable.

The Relative Sterilizing Efficiency of Various Chemical Substances Used as Soil Antiseptics.

The use of various chemical substances for the purpose of sterilizing soil has long been practiced not only in the laboratory, but in the greenhouse and under field conditions as well. Russell and Hutchinson (12), and recently Buddin (1), have made an extensive survey of substances which would prove adequate in presenting the so-called "partial sterilization" phenomena. The results obtained by the former investigators indicate that volatile antiseptics in quantities of one per cent are as efficient as when used in greater amounts. For this reason one per cent (on the

basis of 100 gm. of air-dry soil) of the following volatile antiseptics were employed: ethyl alcohol (C_2H_5OH), ethyl ether [$(C_2H_5)_2O$], hydrogen peroxide (H_2O_2), toluene ($C_6H_5CH_3$), carbon bisulfid (CS_2), and chloroform ($CHCl_3$).

The procedure of this experiment was as follows: 100-gm. portions of Penn Clay Loam (passing a 20-mesh sieve) were placed in cotton-plugged 200 c.c. Erlenmeyer flasks. The soil was then brought to optimum moisture content by the addition of 25 c.c. of sterile tap water. One per cent quantities of the above-mentioned volatile antiseptics were then added to the soil. Each treatment was carried out in duplicate. In the case of the addition of hydrogen peroxide, 5 c.c. of concentrated solution were previously added to 20 c.c. of sterile tap water and the mixture used to bring the soil to the optimum moisture content. Following the addition of the antiseptics the flasks were sealed with corks which had previously been steeped in paraffine. The antiseptics were allowed to remain in contact with the soil for 3 days at room temperature. At the expiration of this time, the paraffine corks were removed from the flasks, and sterile cotton plugs substituted. In their work on partial sterilization, Russell and Hutchinson (11) removed the volatile antiseptics from the soil after treatment, by exposing the latter to the air for a time. It would be practically impossible to accomplish this under sterile conditions, consequently the following apparatus, illustrated in figure 2, was devised.

The vacuum chamber (A) is a strong metal tank (in this case a fire extinguisher emptied of its contents was employed), which is connected with a water-pump (F) for exhausting the air from the chamber. Another connection is made with the barometer (I), which consists of a graduated glass tube inverted in a bottle of mercury. In a subsequent portion of this paper mention will be made of the volatilization of antiseptics by immersion of a bottle of antiseptic (D) in boiling water (E). This connection is likewise indicated in the diagram. Stop-cocks were placed at the points marked C. It might be added parenthetically that the capacity of the vacuum chamber (A) in which the flasks (B) were placed is 11,500 c.c.

In the experiment under discussion the flasks (B) were placed in the vacuum chamber (A) and the latter exhausted (G) to one-half inch mercury pressure (F). After remaining in the chamber for one-half hour, the flasks were removed and the soils plated out on Lipman and Brown's (5) synthetic agar for bacterial counts in the usual manner. The total water-soluble solids were determined by the method previously described under the sterilization of soil by intermittent dry heat. An examination of the soils for the presence of any antiseptics, revealed the fact that toluene was the only substance remaining in any appreciable quantity in the soil after such treatment.

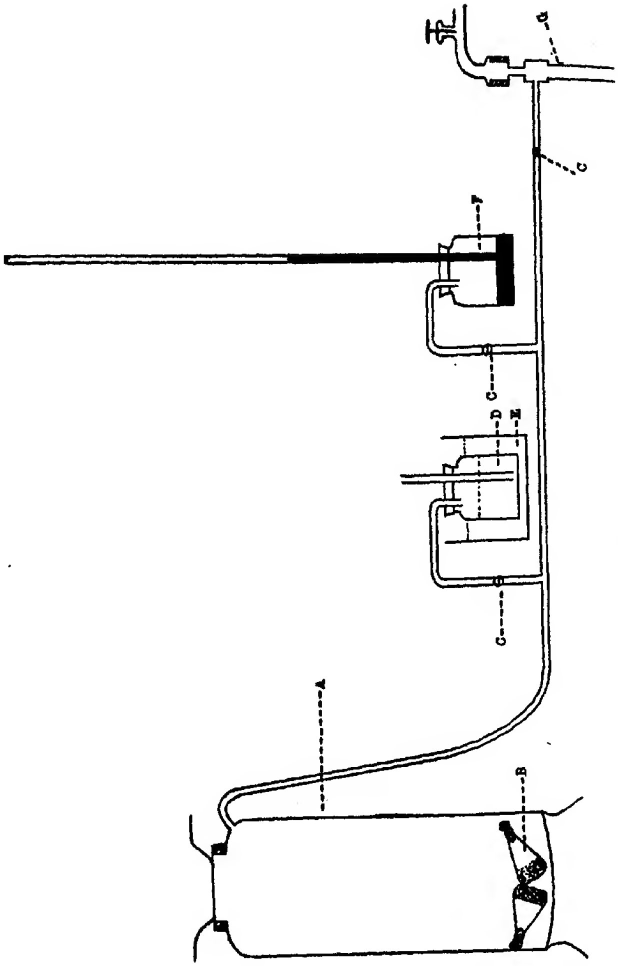

Fig. 2. Diagram of apparatus used in experiment on sterilizing soil with various antiseptics.

It will be seen from the results in Table III that this method of applying antiseptics is not sufficiently efficient to justify its use as a practical means of soil sterilization. Of the substances employed, chloroform,

TABLE III.

THE RELATIVE EFFICIENCY OF VOLATILE ANTISEPTICS (1%) IN SOIL STERILIZATION.

MOIST SOIL.

Lab. No.	Antiseptic	Bacteria in millions per gm. of soil	Average	Total Water-soluble Solids, Av. in gm.
210	Original Soil		47.75	.0220
298	Check	44.50		
299	Check	51.00	47.75	.0902
334	Alcohol (Ethyl)	44.50		
335	Alcohol (Ethyl)	42.50	43.50	.1045
300	Ether (Ethyl)	41.50		
301	Ether (Ethyl)	37.00	39.25	.1090
322	Hydrogen Peroxide	41.00		
323	Hydrogen Peroxide	26.50	33.25	.0990
310	Toluene	11.50		
311	Toluene	27.00	19.25	.0947
328	Carbon Bisulfid	13.50		
329	Carbon Bisulfid	5.50	9.50	.1097
316	Chloroform	9.00		
317	Chloroform	4.50	6.75	.0915

carbon bisulfid, and toluene, in the order named, were effective in decimating the bacterial flora; chloroform being responsible for a decrease of 86 per cent of the original bacterial content. Furthermore, chloroform caused the least alteration in the chemical constitution of the soil, as indicated by the total water-soluble solids, which in this case amounted to something more than three times the original quantity present.

Under the conditions of the experiment, volatile antiseptics when applied to moist soil in amounts of 1 per cent were not efficient as sterilizing agents. Acting upon the assumption that dry soil is more difficult to sterilize than moist soil, the plan of repeating this experiment with air-dry soil was abandoned.

The Relative Efficiency of Volatile Antiseptics Applied as Vapor in Partial Vacuum.

The problem of equal distribution throughout the soil mass is a serious one in the application of volatile antiseptics in such small amounts as 1 per cent. Obviously, moist soil is superior to dry soil in facilitating uniform distribution; nevertheless, it would be of advantage to increase the efficiency even of the former, in this direction. With this in view, the vacuum chamber (figure 2) previously described was adapted to the needs of the following experiment.

The principle involved is, in effect, the application of volatile antiseptics *in vacuo*, thus obtaining an intimate and uniform mixture of soil and chemical. A further modification has been introduced which is based upon the fundamental physical law that gases diffuse more rapidly than liquids; namely, the volatile antiseptics are applied in the form of vapor rather than in the usual liquid state. This combination of the two principal factors of vapor and vacuum is effected by means of the apparatus devised; ergo, a more uniform distribution of the antiseptics in the soil is achieved.

As in former cases, 100-gm. portions of soil were placed in Erlenmeyer flasks (plugged with cotton). In the first series of treatments air-dry soil was employed, whereas in the second series moist soil was used. The volatile antiseptics tested were: osmic acid, ethyl ether, carbon bisulfid, toluene, and ethyl alcohol.

The method of procedure was as follows: The flasks containing soil were placed in the vacuum chamber (A—see figure 2), and the latter exhausted to one-half inch of mercury pressure (F). A bottle containing the antiseptic (D) was immersed in boiling water (E), in order that the application might be made in the form of vapor. By means of a direct connection the vapor entered the vacuum chamber. The flasks were allowed to remain in this antiseptic atmosphere for one and one-half hours, thereby allowing the soil to take up as much vapor as it could. The vacuum chamber (A) was kept in close proximity to a source of heat in order that the antiseptic might remain in a volatile state. During the course of the various treatments pressure was developed within the vacuum chamber as a result of the antiseptics passing from the liquid to the gaseous state. Indirectly, this development of pressure may be considered as being indicative of the fact that the antiseptic vapor has saturated the pore spaces of the soil, which had previously been exhausted.

After the antiseptic vapor had been allowed to remain in intimate contact with the soil for one and one-half hours, the vacuum chamber was again exhausted to one-half inch of mercury pressure in order that the antiseptics might be removed from the soil. Air, which had been rendered sterile by filtering through cotton, was then admitted to the vacuum chamber, and the soils plated immediately for the bacterial count. The process outlined above was repeated on each of three successive days and the total water-soluble solids determined at the conclusion of that period.

It will be observed from the results recorded in Table IV that carbon bisulfid, toluene, and ethyl alcohol, in the order named, were quite effective in decreasing the bacterial content of the air-dry soil, as is evidenced by the fact that the number of bacteria fell from 43,000,000 to 160,000 in the case of the carbon bisulfid and to 250,000 and 330,000 as a result

of treatment with toluene and ethyl alcohol, respectively. In effect, this is a decrease of more than 99 per cent of the original soil flora.

TABLE IV.

THE RELATIVE EFFICIENCY OF VOLATILE ANTISEPTICS APPLIED AS VAPOR IN PARTIAL VACUUM.

AIR-DRY SOIL.

Antiseptic	Bacteria in millions per gram of soil						Total Water-Soluble Solids Av. in gm.	Pressure developed during treatment
	1st Day	Av.	2d Day	Av.	3d Day	Av.		
Original Soil		43.05		43.05		43.05	.0220	
Check	10.00		8.80		4.80			
Check	9.00	9.50	8.00	8.40	4.20	4.50	.0890	29 in. Hg.
Osmic Acid	7.85		6.50		5.00			
Osmic Acid	7.95	7.90	10.00	8.75	2.70	3.85	.0895	28 " "
Ethyl Ether	3.60		3.40		2.75			
Ethyl Ether	3.50	3.55	2.70	3.05	2.00	2.37	.0975	20 " "
Carbon Bisulfid	3.50		0.80		0.12			
Carbon Bisulfid	lost	3.50	0.80	0.80	0.20	0.16	.1190	20 " "
Toluene	6.90		5.10		0.29			
Toluene	8.00	7.45	lost	5.10	0.21	0.25	.1190	12 " "
Ethyl Alcohol	2.20		2.50		0.30			
Ethyl Alcohol	2.10	2.15	2.70	2.60	0.36	0.33	.1195	4½" "

In considering the decrease in bacterial numbers from day to day as a result of treatment, in the case of carbon bisulfid there is a decrease on the second day 75 per cent of the number of bacteria present on the first day, followed by a decrease on the third day of 80 per cent of the number present on the second day. There is, then, good reason to believe that if the treatment were prolonged over a greater period of time, the number of bacteria might be still further reduced. The operation of the time-factor, however, must be regarded as a distinct limitation upon any method of protracted duration. With toluene and ethyl alcohol there is likewise a striking reduction in numbers from the second to the third day. It will be noted in this experiment that osmic acid proved to be unsuccessful as a sterilizing agent for soil. Ethyl ether, as well, was found to be inefficient.

With regard to the total water-soluble solids it will be observed that there is, generally speaking, a fourfold increase. No correlation can be established between the sterilizing efficiency of the antiseptics in question, and the pressure developed by them in the gaseous state during treatment, although the data may not be altogether without interest.

It may be seen from Table V that the final results for moist soil are similar to those obtained where dry soil was employed, with the exception of ethyl ether which yields the largest reduction of bacterial num-

bers. Carbon bisulfid, toluene and ethyl alcohol again manifest a fair degree of efficiency, although their effectiveness is not as great in moist soil as in dry soil. This may possibly be explained on the grounds that in the case of the moist soil the bacteria had ample opportunity to multiply in the 24-hour interval between sterilizations; or, on the other hand, it is not impossible to suppose that the moist soil offers greater resistance to the penetration of the antiseptic vapors than the dry soil. The reduction in bacterial numbers on successive days is noteworthy, although not quite so marked as in the treatment of dry soil.

TABLE V.

THE RELATIVE EFFICIENCY OF VOLATILE ANTISEPTICS APPLIED AS VAPOR IN PARTIAL VACUUM.

MOIST SOIL.

Antiseptic	Bacteria in millions per gram of soil						Total Water-Soluble Solids Av. in gm.	Pressure developed during treatment
	1st Day	Av.	2d Day	Av.	3d Day	Av.		
Original Soil		47.75		47.75		47.75	.0220	
Check	8.30		5.30		3.90			
Check	8.00	8.15	4.80	5.05	3.60	3.75	.0895	29 in. Hg.
Osmic Acid	3.50		4.00		4.70			
Osmic Acid	2.70	3.10	4.90	4.45	2.00	3.35	.0860	28 " "
Ethyl Ether	3.00		1.10		0.15			
Ethyl Ether	4.50	3.75	0.92	1.01	0.20	0.17	.1215	20 " "
Carbon Bisulfid	10.00		0.70		0.50			
Carbon Bisulfid	13.00	11.50	0.70	0.70	0.46	0.48	.1145	20 " "
Toluene	4.30		1.80		1.60			
Toluene	4.40	4.35	0.70	1.25	0.63	1.11	.0950	12 " "
Ethyl Alcohol	6.70		2.20		1.00			
Ethyl Alcohol	6.80	6.75	2.70	2.45	1.20	1.10	.1190	4⅜" "

The superiority of osmic acid over the check treatment is virtually insignificant. The treatments employed were responsible for an increase in total water-soluble solids, as formerly, of approximately four times the original amount. From the data presented in Tables IV and V it may be inferred that volatile antiseptics applied as vapor in partial vacuum are relatively efficient in the sterilization of soil. This method, if sufficiently prolonged, might render the soil totally sterile, yet the increase in water-soluble constituents must also be considered, and with this point in view it is evident that the soil is compelled to undergo some alteration.

The Relative Efficiency of Volatile Antiseptics When Applied Under Heat and Pressure.

Having obtained results of a somewhat encouraging nature from the use of intermittent heat at 82° C., it was deemed advisable to combine this method with a still further modification of the application of volatile antiseptics, namely, employing the latter under pressure at 80° C. for three successive days. It was observed in the preceding experiment that when antiseptics were vaporized in an air-tight chamber they automatically developed pressure.

The method of procedure was as follows: A vertical steam pressure autoclave (American Standard), commonly employed in the bacteriological laboratory for sterilization, was filled to within 5 inches of the top with water and the temperature raised to 80° C. An agate pan was floated on the surface of the water and the Erlenmeyer flasks (plugged with cotton) containing moist soil were placed therein. One hundred cubic centimeters of the volatile antiseptics under investigation were poured into the agate pan. The lid of the autoclave was then quickly clamped down and the check valve closed upon the appearance of the vapor. As a result of the vaporization of the antiseptic, pressure was developed. (It is assumed throughout this work with volatile antiseptics that the usual precautionary methods are observed, and all flames in the vicinity of the vapors extinguished.) The flasks were allowed to remain in the autoclave for one hour,[1] after which they were removed to the vacuum chamber, which was exhausted to one-half inch mercury pressure. After remaining in the chamber for one-half hour to allow sufficient time for the removal of the antiseptic, sterile air was admitted and the soils plated immediately for bacterial counts. The entire 100 gm. of soil were taken up with one liter of sterile water and the ordinary dilutions employed. It was impracticable to use alcohol in this experiment for the reason that it would remain in solution in the water.

From the results in Table VI it will be noted that this method of treatment was fairly effective in depopulating the bacterial flora of the soil. The decrease, in general, approximated 98 per cent. Carbon bisulfid was the only antiseptic employed that proved superior to the check treatment. In this case a possible correlation might be obtained between the pressure developed during treatment and the effectiveness of the sterilizing agent. Thus carbon bisulfid developed a pressure of 20 pounds, whereas ethyl ether, which proved least efficient in sterilization, developed only 6 pounds of pressure. Carbon tetrachloride, with only 5 pounds pressure, is an exception to such a generalization.

[1] During the period of treatment the temperature fell, on the average, ten degrees.

TABLE VI.

THE RELATIVE EFFICIENCY OF VOLATILE ANTISEPTICS APPLIED UNDER HEAT AND PRESSURE.

MOIST SOIL.

Antiseptic	Bacteria in millions per gram of soil						Total Water-Soluble Solids Av. in gm.	Pressure developed during treatment
	1st Day	Av.	2d Day	Av.	3d Day	Av.		
Original Soil		47.75		47.75		47.75	.0220	
Check	10.00		1.27		0.55			
Check	9.00	9.50	1.17	1.22	0.65	0.60	.0885	0
Carbon Tetrachloride	11.50		1.17		0.45			
Carbon Tetrachloride	12.50	12.00	2.60	1.88	0.80	0.62	.1097	5 lbs.
Carbon Bisulfid	10.50		0.41		0.30			
Carbon Bisulfid	6.50	8.50	0.34	0.37	0.15	0.22	.1170	20 "
Ethyl Ether	9.50		0.96		1.55			
Ethyl Ether	11.50	10.50	0.75	0.85	1.30	1.42	.1102	6 "
Chloroform	8.50		1.50		0.95			
Chloroform	4.50	6.50	1.50	1.50	0.80	0.87	.1055	10 "

In the matter of total water-soluble solids, the increase is again approximately fourfold. This experiment was repeated, substituting air-dry for moist soil, with little or no increase in effectiveness of volatile antiseptics over the check treatment.

In a general comparison of the volatile antiseptics employed under the various treatments as outlined, shown in Table VII, the total decrease (in per cent) of the bacterial numbers from the original bacterial content of the soil is recorded, as well as the increase in total water-soluble solids (in per cent) over the amount originally present in the soil.

Under the conditions of this experiment it will be readily observed from the calculations represented in Table VII that intermittent dry heat at 82° C. for 5 successive days in moist soil was responsible for the greatest bacterial decrease, or 99.996 per cent. Likewise, this method caused the minimum alteration in the chemical constitution of the soil as indicated by the amount of total water-soluble solids. It is of interest to note that, whereas the above method caused a 46 per cent increase of total water-soluble solids, the ordinary moist heat sterilization at 120° C. for 15 minutes at 15 pounds pressure, which is widely used in soil biology investigations, caused an increase of 720.45 per cent. Thus it is evident that the latter method induces a radical alteration in the composition of the soil compared with the former.

Of the three other methods devised, that of applying volatile antiseptics in partial vacuum for three successive days proved somewhat superior to the application of these chemicals under heat (80° C.) and pressure for a similar period. Volatile antiseptics applied in 1 per cent. quantities in the liquid state are inefficient. Carbon bisulfid, in general,

proved to be the most efficient volatile antiseptic tested with regard to its practical value as a sterilizing agent. The three methods just mentioned caused approximately a fourfold increase in total water-soluble solids.

TABLE VII.

COMPARISON OF THE VOLATILE ANTISEPTICS EMPLOYED UNDER VARIOUS TREATMENTS SHOWING TOTAL DECREASE (IN PER CENT) OF BACTERIAL NUMBERS FROM ORIGINAL BACTERIAL CONTENT OF THE SOIL; AND INCREASE OF TOTAL SOLIDS (IN PER CENT).

Treatment	Total decrease of bacterial numbers resulting from treatment (av.)							
	1% applied as liquid 3 days in moist soil		Partial Vacuum 3 Days				Pressure and heat (80° C.) for 3 days	
			Moist Soil		Air-Dry Soil			
	Bact. Dec. %	Total Solids Inc. %	Bact. Dec. %	Total Solids Inc. %	Bact. Dec. %	Total Solids Inc. %	Bact. Dec. %	Total Solids Inc. %
Original Soil—Ck. Treatment.		310.00	92.15	306.81	89.55	304.54	98.75	302.27
Carbon Tetrachloride							98.71	398.63
Carbon Bisulfid	80.11	394.08	99.00	420.45	99.63	440.90	99.54	431.81
Ethyl Ether	17.80	395.45	99.65	452.27	94.50	343.18	97.03	400.91
Chloroform	85.87	315.89					98.18	379.54
Osmic Acid			92.98	290.91	91.06	306.81		
Toluene	59.69	330.45	97.68	331.81	99.43	440.90		
Ethyl Alcohol	8.91	375.00	97.70	440.91	99.24	443.18		
Hydrogen Peroxide	30.37	350.00						
	Moist Soil		Air-Dry Soil					
Intermittent Dry Heat at 82° C. for 5 days	99.996	45.91	91.96	13.63				
Moist Heat at 120° C. for 15 min. at 15 lbs. pressure.....	Sterile	720.45						

The data presented above are preliminary in character, and although no definite conclusions can be established, several lines of investigation are indicated which might prove adequate in solving the problem of soil sterilization without radical alteration.

Summary.

1. Under the conditions of the experiment, with Penn Clay Loam, intermittent sterilization by means of dry heat at 82° C. for 5 successive days in moist soil, almost completely decimated the bacterial flora of the soil. This was accomplished with but a slight change in the chemical constitution of the soil, as indicated by the amount of water-soluble solids. Ordinary steam sterilization under pressure causes a change sixteen times as great.

2. There is a strong indication that the application of volatile antiseptics either in partial vacuum or under a combination of heat and pressure, if repeated for more than three successive days, would achieve complete soil sterilization without involving any radical alteration in the chemical constitution of the soil.

In conclusion, it is a privilege to express an appreciation of Dr. J. G. Lipman's suggestions, ever at our disposal.

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INCUBATION STUDIES WITH SOIL FUNGI.[1]

By S. A. Waksman, *Research Assistant, Agricultural Experiment Station,* and R. C. Cook, *Research Fellow, Rutgers College.*

Introduction.

Recent investigations in the field of microbiology have shown in a measure the importance of recognizing fungi as one of the factors in soil fertility. In studying the complex problem of microörganic activities, too little attention has been directed to the possible influence of fungus forms. In fact, many of the chemical changes taking place constantly in soils have been considered almost wholly the result of bacterial life, while now we know that a large number of fungi are capable of working in some directions quite as efficiently as bacteria. Whether or not fungi have the capacity to fix nitrogen or to nitrify, cannot be definitely settled as yet, but many of them do have the power to ammonify. Their importance is thus further emphasized by the fact that they occur in such large numbers in cultivated and uncultivated soils.

Since the morphology and life history of fungi are much more complex than those of bacteria, we have reason to suspect that the development of different stages in the life of these organisms may simultaneously affect their powers to decompose organic matter; whereas the very short life cycle of bacteria renders their functions in the soil a more or less continuous process, the fact that fungi have a much longer life cycle would no doubt affect their relation to the fertility of the soil differently at successive stages of growth.

In order to learn something of the factors involved in this phase of biological activities, the present investigations were begun.

Experimental.

The character of this study was such that in the very beginning the usual methods of working with soil fungi were questioned. In general, these methods were essentially the ones used in work with bacteria, and the adaptability was thereby merely assumed. It was therefore planned to carry out a few preliminary experiments in an effort to determine two important elements: first, moisture requirements; and second, the proper incubation period.

The soil used throughout was a Sassafras gravelly loam, dried blood and cottonseed meal serving as ammoniates. Three organisms were employed as follows: *Mucor plumbeus, Penicillium sp.,*[2] and *Monilia sito-*

[1] Received for publication September 15, 1915.

[2] This organism belongs to a group of soil Penicillia which are at present under investigation.

phila. These were isolated and purified on the fungi medium noted below.[1] Subcultures were made in liquid media of the same composition and incubated at 25° C. until spores were produced. One-cubic centimeter portions of these cultures were used for inoculation.

Series I.

Moisture Relationship and Incubation Period.

In this series four different amounts of moisture were tried. The organic matter, in quantities containing 100 mg. of nitrogen, was added to fifty-gram portions of soil and thoroughly mixed. The physical optimum of the mixtures was then determined (16 per cent resulting for the soil with dried blood and 17 per cent for the soil with cottonseed meal). The moisture was varied and added as noted below; 1 c.c. in excess being added to all to allow for loss during sterilization which was accomplished at 15 pounds pressure for 15 minutes. The soil portions were properly inoculated and subsequently incubated at 22° C. These were divided into three sets, a set being distilled for ammonia after six, twelve, and eighteen days respectively. *Mucor plumbeus* and *Penicillium sp.* were used for inoculation.

TABLE I.

AMMONIFICATION BY MUCOR PLUMBEUS AND PENICILLIUM SP. IN 6 DAYS.

Moisture added	Organic comp.	Check		Mucor plumbeus			Penicillium sp.		
		Amm'ia N found		Ammonia N found			Ammonia N found		
		mg. N	Ave'ge	mg. N	Ave'ge	Inc. over check	mg. N	Ave'ge	Inc. over check
	100 mg. N. in	2.2		3.20			5.10		
¼ optimum	Dried Blood	2.4	2.30	4.40	3.80	1.50	6.50	5.80	3.50
		2.2		5.80			8.65		
½ "	"	2.2	2.20	8.10	6.95	4.75	8.30	8.48	6.28
		2.3		14.65			10.20		
1 "	"	2.2	2.25	13.45	14.05	11.80	9.50	9.85	7.60
		2.3		12.55			9.30		
2 "	"	2.3	2.30	12.85	12.70	10.40	10.30	9.80	7.50
	100 mg. N. in	2.6		8.65			3.75		
¼ optimum	Ctn Sd Meal	2.6	2.60	7.55	8.10	5.50	3.60	3.68	1.08
		2.3		12.60			3.40		
½ "	"	2.4	2.35	12.80	12.70	10.35	3.40	3.40	1.05
		2.4		13.75			3.15		
1 "	"	2.5	2.45	13.60	13.68	11.23	3.15	3.15	.70
		2.3		9.80			3.15		
2 "	"	2.3	2.30	11.60	10.70	8.40	3.45	3.30	1.00

[1] Medium No. II as described in "The relation of parasitic fungi to the contents of the cells of the host plants," Cook, M. T., and Taulenhaus, M. S., Del. Agr. Exp. Stat., Bul. 91, p. 11.

Table I shows that the amount of ammonia accumulation in six days by *Mucor plumbeus* from both dried blood and cottonseed meal increases from one-fourth optimum to optimum moisture and then slightly decreases. Essentially the same conditions are true with *Penicillium sp.* except that with cottonseed meal the ammonia accumulation was so little that differentiation was difficult.

TABLE II.

AMMONIFICATION BY MUCOR PLUMBEUS AND PENICILLIUM SP. IN 12 DAYS.

Moisture	Organic comp.	Check		Mucor plumbeus			Penicillium sp.		
		Amm'ia N found		Ammonia N found			Ammonia N found		
		mg. N	Ave'ge	mg. N	Ave'ge	Inc. over check	mg. N	Ave'ge	Inc. over check
	100 mg. N. in	2.3		6.60			13.15		
¼ optimum	Dried Blood	2.4	2.35	6.50	6.55	4.30	16.50	14.83	12.48
		2.1		10.00			23.00		
½ "	"	2.8	2.45	14.00	12.00	9.55	26.20	24.60	22.15
		2.1		19.80			26.20		
1 "	"	2.6	2.35	19.70	19.75	17.15	25.10	25.65	23.30
		2.1		20.40			24.05		
2 "	"	2.2	2.15	lost	20.40	18.25	20.40	22.23	20.08
	100 mg. N. in	2.4		17.50			8.00		
¼ optimum	Ctn Sd Meal	2.8	2.60	15.70	16.60	14.00	8.80	8.40	5.80
		2.3		20.80			7.50		
½ "	"	3.3	2.80	21.00	20.90	18.10	12.25	9.88	7.08
		2.4		22.55			12.50		
1 "	"	2.8	2.60	21.15	21.85	19.25	lost	12.50	9.90
		2.2		18.60			12.60		
2 "	"	2.9	2.55	23.10	20.85	17.95	12.00	12.30	9.40

In Table II we find that in twelve days also the ammonia accumulation goes hand in hand with the increase in moisture up to optimum, beyond which it decreases.

The eighteen-day period again shows that the optimum physical moisture corresponds closely to the optimum moisture conditions for the fungi, except in the case of the cottonseed meal, where one-half optimum gave better results.

The fact that moisture variation has not seemed to alter appreciably the behavior of the organisms at different periods, permits us to see at once the effect of time of incubation upon ammonia accumulation.

With the *Mucor* the increase from the sixth to the twelfth day was marked, while no appreciable advantage was gained by incubating eighteen days. However, with the *Penicillium,* in eighteen days there was still a large increase over that obtained at twelve days. But if we turn to Table III we find that with cottonseed meal less ammonia was noted at optimum than at one-half optimum, a point which might indicate that some other

process had started, thus consuming the ammonia where there was sufficient moisture. This fact in itself would tend to warrant the choice of a twelve-day period. One can easily see how the length of incubation might alter the relationship between organisms in ammonification studies.

TABLE III.

AMMONIFICATION BY MUCOR PLUMBEUS AND PENICILLIUM SP. IN 18 DAYS.

Moisture	Organic comp.	Check		Mucor plumbeus			Penicillium sp.		
		Amm'ia N found		Ammonia N found			Ammonia N found		
		mg. N	Ave'ge	mg. N	Ave'ge	Inc. over check	mg. N	Ave'ge	Inc. over check
	100 mg. N. in	1.9		4.40			20.4		
¼ optimum	Dried Blood	1.8	1.85	4.20	4.30	2.45	21.8	21.10	19.25
		1.9		13.15			31.1		
½ "	"	2.2	2.05	14.05	13.60	11.55	30.2	30.65	28.60
		1.8		21.90			36.3		
1 "	"	1.8	1.80	22.90	22.40	20.60	35.7	36.00	34.20
		1.8		21.00			32.7		
2 "	"	1.6	1.70	21.70	21.35	19.65	30.3	31.50	29.80
	100 mg. N. in	1.9		20.45			12.6		
¼ optimum	Cot's'd Meal	1.6	1.75	19.25	18.85	18.10	19.9	16.25	14.50
		1.9		24.50			19.2		
½ "	"	2.1	2.00	23.70	24.10	22.10	19.9	19.55	17.55
		2.1		22.00			17.4		
1 "	"	1.8	1.95	23.50	22.75	20.80	16.9	17.15	15.20
		2.1		20.60			15.5		
2 "	"	lost	2.10	20.40	20.50	18.40	16.8	16.15	14.05

In the work of McLean and Wilson,[2] where fungi were compared as to their capacity to ammonify, a seven-day period was employed. Had a longer period been chosen, which would have given the slower ammonifiers time to develop, no doubt different results would have been obtained. The *Aspergillaceae* group was found in their work to be composed of weak ammonifiers, and the *Mucors* of strong ammonifiers. It is interesting to note and compare the results obtained in the above tables with those in the work referred to. In ammonia accumulation the *Mucor* led by a large margin the *Penicillium,* a member of the *Asperagillaceae* group, with both dried blood and cottonseed meal for the six-day period. However, in twelve days the *Penicillium* with dried blood surpassed the *Mucor,* and nearly equalled it with cottonseed meal, holding this relationship through the eighteenth day. It appears that with slow growing organisms a longer period of incubation is necessary to secure truly characteristic activity.

In an effort to determine whether or not the biological stage of the fungi bears any relationship to their capacity to accumulate ammonia, the preliminary experiments served as a guide to the following plan.

[2] McLean and Wilson, Ammonification Studies with Soil Fungi. N. J. Agr. Exp. Sta., Bulletin 270, 39 p., 1 pl.

SERIES II.

The Biological Stage of Fungi as Affecting Ammonification.

The organisms, soil, and organic matter were the same as noted above. One hundred grams of soil were placed in Erlenmeyer flasks of 250 c.c. capacity, thoroughly mixed with the organic matter in portions containing 155 mg. of nitrogen, and brought to optimum moisture condtions. These were then plugged and sterilized as before, after which proper inoculation was made. One cubic centimeter of the inoculum contained spores as follows: *Mucor*, about 1,000,000; *Penicillium*, 100,000-200,000; *Monilia*, 3,000,00-4,000,000. Incubation was effected at about 27° C. Daily determinations of ammonia were made in duplicate for each organism with both organic materials. The development of the organisms was watched daily as well.

TABLE IV.

DAILY ACCUMULATION OF AMMONIA IN THE SOIL BY MUCOR PLUMBEUS.

Period of Incubat'n Days	Dried Blood				Cottonseed Meal			
	Ammonia Nitrogen found				Ammonia Nitrogen found			
	mg. N.	Average	Inc. over check	Daily gain	mg. N.	Average	Inc. over check	Daily gain
	2.35				4.55			
1	2.64	2.50	0.07	0.07	3.97	4.26	0.07	0.07
	3.53				8.82			
2	3.82	3.68	1.25	1.18	8.65	8.74	4.55	4.48
	4.41				12.05			
3	4.85	4.63	2.20	.95	10.44	11.25	7.06	2.51
	5.00				14.70			
4	5.12	5.06	2.63	.43	13.26	13.98	9.79	2.73
	6.47				31.31			
5	6.47	6.47	4.04	1.41	26.75	29.03	24.84	15.05
	6.76				34.10			
6	7.20	6.98	4.55	.51	31.05	32.58	28.39	3.55
	8.06				38.96			
7	8.23	8.15	5.72	1.17	37.53	38.30	34.11	5.72
	8.23				41.31			
8	8.53	8.38	5.95	.23	39.10	40.21	36.02	1.91
	9.56				39.84			
9	12.64	11.10	8.67	2.72	40.87	40.36	36.17	.15
	10.58				41.60			
10	11.17	10.88	8.45	—0.22	40.86	41.23	37.04	.87
	11.32				42.92			
11	10.88	11.10	8.67	0.22	40.72	41.82	37.63	.59
	11.61				42.78			
12	11.73	11.17	8.74	0.07	45.42	44.10	39.91	2.28
	2.44				4.26			
Check	2.42	2.43			4.12	4.19		

In the column of daily gains of ammonia by *Mucor plumbeus*, one sees that the strongest activity occurred about every other day; and from actual observation of the growth of the organism, this seemed to coincide with the times immediately following the periods of active spore formation.

TABLE V.

DAILY ACCUMULATION OF AMMONIA IN THE SOIL BY MONILIA SITOPHILA.

Period of Incubat'n Days	Dried Blood				Cottonseed Meal			
	Ammonia Nitrogen found				Ammonia Nitrogen found			
	mg. N.	Average	Inc. over check	Daily gain	mg. N.	Average	Inc. over check	Daily gain
	2.94				4.85			
1	3.09	3.02	0.59	0.59	5.88	5.37	1.18	1.18
	4.50				33.96			
2	4.70	4.60	2.17	1.58	36.30	35.13	30.94	29.75
	13.38				44.10			
3	13.52	13.45	11.02	8.85	43.66	43.88	39.69	8.75
	20.00				50.86			
4	20.58	20.29	17.86	6.84	51.16	51.01	46.82	7.13
	23.08				51.30			
5	23.52	23.30	20.87	3.01	52.77	52.04	47.85	1.03
	26.17				53.65			
6	26.31	26.24	23.81	2.94	53.94	53.80	49.61	1.76
	27.05				56.30			
7	29.20	28.13	25.70	1.89	53.80	55.05	50.86	1.25
	32.78				57.18			
8	32.49	32.64	30.21	4.51	55.86	56.52	52.33	1.47
	34.69				57.92			
9	34.25	34.47	32.04	1.83	58.95	58.44	54.25	1.92
	39.39				59.68			
10	lost	39.39	36.96	4.92	61.25	60.47	56.28	2.03
	39.54				59.53			
11	40.13	39.84	37.41	.45	60.86	60.20	56.01	—0.27
	41.01				60.71			
12	41.90	41.46	39.03	1.64	59.09	59.90	55.71	—0.30
	2.44				4.26			
Check	2.42	2.43			4.12	4.19		

Monilia sitophila, known to be a very strong ammonifier, showed in this series the accumulation of large quantities of ammonia even in the first days of incubation. With dried blood, about half of the total amount registered for twelve days was accumulated in four days, while with cottonseed meal about 80 per cent was accumulated in the same length of time. Or, in other words, at least 15 per cent of the total nitrogen in dried blood and 30 per cent of that in cottonseed meal, had been ammonified in four days. Spores were abundant here in the early stages of growth, particularly about the second and third days, the greater number occurring earlier in the cottonseed meal cultures. The correlation between sporulation and ammonia accumulation seems again to hold true.

Turning to Table VI, one finds that very little ammonia accumulated within the first six days by *Penicillium sp.,* and only on the seventh day was a marked increase in ammonia noticed. Up until the sixth and seventh days there was no notable sporulation, but principally development of mycelium. Extensive sporulation was observed beginning at

this period and about every two or three days thereafter. The figures in this table after the six-day period show a similar variation in the amount of ammonia accumulated.

TABLE VI.

DAILY ACCUMULATION OF AMMONIA IN THE SOIL BY PENICILLIUM SP.

Period of Incubat'n Days	Dried Blood				Cottonseed Meal			
	Ammonia Nitrogen found				Ammonia Nitrogen found			
	mg. N.	Average	Inc. over check	Daily gain	mg. N.	Average	Inc. over check	Daily gain
1	2.77 2.69	2.73	0.33	0.33	4.23 4.07	4.15	—0.04	—0.04
2	2.36 2.48	2.42	0.02	—0.31	4.06 4.06	4.06	—0.13	—0.09
3	3.20 2.91	3.06	0.66	0.64	4.50 4.22	4.36	0.17	0.30
4	4.05 3.72	3.89	1.49	0.83	4.89 5.12	5.01	0.82	0.65
5	4.66 4.95	4.82	2.42	0.93	6.55 5.96	6.26	2.07	1.25
6	4.80 5.39	5.10	2.70	0.28	7.72 7.72	7.72	3.53	1.46
7	7.94 6.76	7.35	4.95	2.25	15.73 16.61	16.17	11.98	8.45
8	8.08 9.42	8.75	6.35	1.40	18.41 18.86	18.64	14.45	2.47
9	10.88 9.26	10.07	7.67	1.32	25.73 26.90	26.32	22.13	7.68
10	11.83 12.20	12.02	9.62	1.95	26.46 27.56	27.01	22.82	0.69
11	15.88 16.76	16.32	13.92	4.30	36.82 34.54	35.68	31.49	8.67
12	15.88 17.40	16.64	14.24	.32	37.90 38.80	38.35	34.16	2.67
13	19.55 19.25	19.40	17.00	2.76	41.60 41.44	41.52	37.33	3.17
14	22.05 23.50	22.78	20.38	3.38	43.12 46.60	44.86	40.67	3.34
15	27.20 28.66	27.93	25.53	5.15	48.95 47.33	48.14	43.95	3.28
Check	2.40 2.40	2.40			4.26 4.12	4.19		

The curves give a graphical expression to the foregoing statements and show to some extent the behavior of the individual organisms accentuating the variability in daily gains of ammonia. Attention is called to the fact that in general there is a period of low activity in the beginning, followed usually by a period of maximum activity, and later by one of lesser and varying activity. The intensity of the period of maximum activity has its reaction in the subsequent growth of the organism, as is to be expected, when there is a point of very large ammonia accumulation. The later development is more uniform, but where there is no such point of extreme activity the periods of extensive ammonification alter-

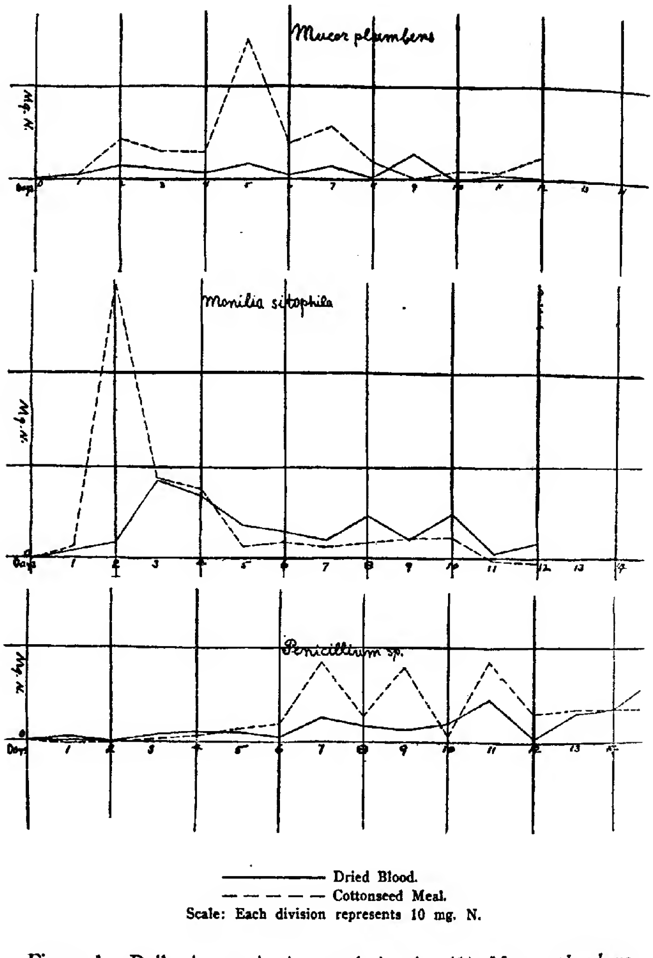

Figure 1.—Daily Ammonia Accumulation by (1) *Mucor plumbeus,* (2) *Monilia sitophila,* and (3) *Penicillium sp.*

nate with comparatively inactive ones. Each organism seems to have its own peculiarities in this respect. The application becomes of importance in considering data secured with different fungi. For instance, two or more organisms compared may give on one day a certain relationship to each other, while on another day this relationship may not exist, depending upon the respective sporulation periods.

It must not be understood, however, that ammonia accumulation depends upon sporulation; rather, it seems to follow it closely. The maximum gain in ammonia coincides with the germination of the spores and the subsequent development of the mycelium; while the minimum gain occurs when the organism prepares itself to produce new spores. While spore production may be a more or less continuous process, there are, however, well defined periods when it is the predominant activity of the organism.

A good analogy is found in the growth of legumes like the clovers. Nitrogen is fixed during the period of active growth of the plant, the fixation ceasing almost entirely when seed formation begins. In a like manner most of the ammonia seems to be accumulated when the spores of the fungus germinate to form new mycelium, this process being appreciably hindered at the time at which the organism forms its sporophores immediately preceding the complete development of the corresponding spores.

The three fungi studied represent three very important groups of soil organisms, and their behavior should therefore be indicative of the activities of those groups of which they are members. *Monilia sitophila* represents the Moniliaceae, which are strong ammonifiers, accumulating most of their ammonia in a very short period of time. This is undoubtedly due to their early and extensive spore formation. In contrast to the Moniliaceae, the Aspergillaceae, of which the *Penicillium sp.* is a member, are weak ammonifiers in short incubation periods; but if the period of incubation is sufficiently long, large quantities of ammonia will be accumulated. *Mucor plumbeus,* representing a third important group of soil organisms, places itself intermediate between the two above.

Taken collectively, the experiments show that there is an important connection between the biological stage of a fungus and its capacity to decompose organic matter as indicated by ammonia accumulation.

Summary.

The results of these experiments indicate that:

1. Optimum moisture conditions for ammonia accumulation by fungi lie near the physical optimum.

2. The proper incubation period depends entirely upon the organism.

3. A twelve-day incubation period is preferable to a shorter one for practical work.

4. A correlation exists between the biological stage of the organism and the periods of ammonia accumulation; the largest amount seems to accompany the periods of spore germination and the smallest amount the time preparatory to actual spore formation.

5. *Monilia sitophila* shows the largest ammonia accumulation within the first three or four days; *Penicillium sp.*, between ten and fifteen days; and *Mucor plumbeus*, between six and ten days. These periods correspond to those of active spore formation for the respective organisms.

A PRELIMINARY STATEMENT ON THE PRESENT STATUS OF THE HUMUS NITROGEN PROBLEM IN ARID SOILS.[1]

By Chas. B. Lipman,

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On the basis of analyses of soils for humus and humus nitrogen carried out by the late Professor Hilgard, his associate Professor Loughridge, and their assistants prior to 1912, the two investigators named came to the conclusion that soils of the arid region, while containing less humus than soils of the humid region, also contain a much higher percentage of nitrogen in the humus. This was taken as an indication of a tendency to equalization of the total nitrifiable nitrogen content in soils of the two regions. This view is emphasized in Hilgard's celebrated book entitled "Soils," published in 1907, and is widely quoted in other works on the same subject. Peculiarly enough, only the latter part of Hilgard's view with respect to the tendency toward equalization of the available nitrogen supply in soils of the two regions has been called in question, the facts supporting the first part being assumed to be correct. The criticism referred to was made by Stewart (4) in connection with his discussion of Headden's views on the origin of the "nitre" spots and Hilgard's views on the intensity of nitrification in arid soils. After pointing out on the basis of his studies on the nitrate content of Utah soils that there seems to be no evidence there of intense nitrification, Stewart suggests besides that Hilgard's explanation to the effect that the lack of "nitrogen hungriness" in California and other arid soils is to be accounted for as above pointed out is untenable and is "open to mathematical objections." Just what the "mathematical objections" are the writer is unable to see. It appears that Hilgard reasoned logically and correctly enough that if soils of the arid region contained one-fourth as much humus as soils of the humid region but that the humus in the former was four times as rich in nitrogen as that of the latter that the total nitrogen of the humus portion of the soil organic matter should be the same in both cases. This, it appears to the writer, is a simple arithmetical calculation the correctness of which cannot be questioned, and stands true regardless of the disparity in the nitrogen content of the unhumified organic matter of the

[1] Received for publication February 16, 1916.

two classes of soils. On what he regarded as the correct facts with reference to the nitrogen content of the humus of soils of the two regions, supplemented by the experimental results (1) obtained by him which indicated that unhumified organic matter supported little or no nitrification, Hilgard evidently felt justified in considering that for immediate purposes at least, arid soils were as little likely to be nitrogen hungry as humid soils. Even in the more recent critical work on the humus and humus nitrogen of the soil columns published by Loughridge (3), the author, while not making any claims to the existence of a higher nitrogen content in the humus of arid than in that of humid soils, appears to be still of that general opinion.

Taking all of these observations together, the writer cannot help but feel that with the exception of his ideas on the intensity of nitrification in arid soils which Stewart showed to be questionable, and on which the present writer and his associates soon hope to furnish more evidence of a direct nature, Hilgard's reasoning could be considered correct, but his facts were not correct. The latter is evidenced by the data submitted by Loughridge in the paper above cited, and by those in the writer's possession. In the first place, the humus of arid soils, considered by and large, is actually no richer in nitrogen than that of humid soils; and in the second place, Hilgard's single experiment to prove the superior nitrifiability of humified as against unhumified organic nitrogen is subject to serious criticism in the light of our present-day knowledge of the subject of nitrification.

In connection with some studies (2) made by D. D. Waynick and the writer, on the influence of climate on soil, a number of humus determinations were carried out. These determinations were made by the Grandeau method as modified by Hilgard, using at first only dilute ammonia. When, however, we attempted to determine the nitrogen in the ammonia extract, we found such large quantities of nitrogen in the humus that the figures were not used in connection with the investigation mentioned. It should be added that such high nitrogen figures were obtained after the humus solution had been boiled with magnesia for a period of four hours prior to digestion for the total nitrogen determination. Thinking, therefore, that we might obtain more satisfactory results by employing the recommendation of Hilgard for the use of a dilute solution of one of the fixed alkalies in the humus extraction, for purposes of the nitrogen determination, we used a 3 per cent solution of NaOH for the purpose, and obtained a totally different set of results. This occurred despite the fact that the humus extracts as obtained by the two methods looked about the same and yielded similar volumes of solution of similar color intensity. The figures for the humus and nitrogen determinations on the series of soils above discussed are given in Table I. The values for nitrogen in the humus are given as obtained by both methods.

TABLE I.

HUMUS AND HUMUS NITROGEN IN SURFACE SOILS FROM SOIL EXCHANGE PLOTS

	NH_4OH Extraction		NaOH Extraction	Modified Gunning Method
	% Humus	% N in Humus	% N in Humus	Total % N in soil
California soil undisturbed	1.02	13.72	5.44	.096
California soil disturbed at California	1.00	14.70	4.13	.096
Maryland soil in California	1.22	14.91	4.30	.121
Kansas soil in California	1.05	11.61	5.00	.128
Maryland soil in Maryland	1.19	17.64	5.00	.099
Kansas soil in Maryland	.97	12.26	6.44	.120
California soil in Maryland	1.28	14.84	5.51	.089
California soil in Kansas	1.06	17.92	4.62	.092
Kansas soil in Kansas	1.15	12.78	5.18	.141
Maryland soil in Kansas	1.16	18.70	3.92	.110

In studying the data in Table I we see at once that the figures for nitrogen in the humus, in the case of the ammonia extract of the soils in question must be erroneous, since they indicate, in all but three cases, a larger amount of humus nitrogen than there is of total nitrogen in the soil as determined by the Gunning method. In the second place, it is striking to note the great discrepancy between the nitrogen content of the two humus extracts, the nitrogen of the NaOH extract averaging roughly only one-third as high as that of the ammonia extract. Moreover, the discrepancy is not a regular one which allows of the correction of error by a common factor, but the high value in one extract may become the low value in the other, and vice versa. In the group of soils under discussion, it is interesting to note what may be only accidental, that even the humus content does not differ notably as between the humid and the arid soils. They certainly give little support to the idea that the nitrogen content of arid soils is greater than that of humid soils. If anything, the figures support the contrary idea.

If, perchance, the soils above selected should be objected to on the ground that the arid soil of the group, namely the Davis soil, is an alluvial soil which is not truly arid in character, the following considerations will serve to reply to such objections. In an investigation by P. S. Burgess and the writer on the effects of irrigation on the physical, chemical and bacteriological characteristics of an Imperial Valley soil, which has been under way for more than three years, the humus and humus nitrogen determinations have been carried out among many others. The Imperial soil is of course a strictly arid soil, since the normal rainfall in that region is less than 2 inches a year. The soil has always been collected in a five-foot column, one sample as an average of every foot in depth for five feet being taken. Six semi-annual samplings of this kind have been made. At the first sampling we thought it would be possible to use the ammonia extract for the determination of humus and humus nitrogen. Obtaining by

such means, as in the foregoing case, much higher values for nitrogen in the humus than those obtained by the Gunning method for total soil nitrogen, an NaOH extract was prepared as before and analyzed for nitrogen. The results of the determinations gave a similar contrast between the two methods to that shown in Table I, except that it was more emphatic. Table II, setting forth the comparison, follows:

TABLE II.

HUMUS AND HUMUS NITROGEN IN FIVE-FOOT COLUMN OF IMPERIAL SOIL.

	NH_4OH Extraction		NaOH Extraction	Modified Gunning Method
Imperial Soil	% Humus	% N in Humus	% N in Humus	Total % N
First Foot	.325	22.09	4.73	.016
Second Foot	.325	17.23	5.15	.014
Third Foot	.560	11.25	5.58	.015
Fourth Foot	.375	17.28	4.30	.014
Fifth Foot	.425	16.47	4.73	.018

We note in Table II again the great discrepancy between the nitrogen contents of the NH_4OH and NaOH extracts amounting by averages to more than three times the quantity in the former as in the latter. It will be remembered that this figure is similar to the one obtained by rough comparison in Table I. This circumstance may, however, be merely a coincidence. Again, the highest value for nitrogen in the humus by the NH_4OH extract method corresponds to the figure which is next to the lowest in the NaOH extract series. In Table II further it will be noted as in the case of Table I, that the figures for nitrogen in the humus by the ammonia method are far higher than is possible considering the total nitrogen in the soil. But Table II shows the same to be true in the case of the third foot of the Imperial soil even by the NaOH method. This is probably due to an error in the humus determination and is the only real exception to the rule that the nitrogen in the humus by the NaOH method is seldom as high as, and usually considerably lower than, the total nitrogen in the soil.

Taking together the results given in Tables I and II, we are compelled to conclude that the method of determining humus nitrogen in the ammonia extract of soils is a seriously faulty one, no matter how much care is employed in boiling the extract with magnesia. The method is indeed so faulty as to deserve immediate rejection by all those who are at all concerned with the correct determination of nitrogen in humus. In the second place, if the results above given are considered in connection with the largest part of the humus nitrogen data furnished by Loughridge in the paper above cited, there can be no question that the prevalent belief in the high nitrogen content of the humus of arid soils is in error. The facts in hand do not justify any belief in the higher nitrogen content of the humus in either the arid or the humid group of soils over each other.

GENERAL DISCUSSION.

Almost coeval with the earliest soil investigations of Hilgard and his associates and students at the University of California were their studies on soil humus and humus nitrogen. Some work was reported on that subject in nearly every report of Professor Hilgard until 1904. It is unfortunate that the precise method of humus extraction specifying the form of weak alkali used is not given in every case. By whatever method, however, such extraction was carried out, it appears to have led the investigators mentioned to the same conclusion, namely that the lack of humus in soils of the arid region was largely compensated for by the much larger quantity of nitrogen contained in it as against that of humid soils. As pointed out above, some serious error must have crept into these investigations. The writer is informed verbally by Professor Loughridge, who was associated with Professor Hilgard during the greater part of the latter's scientific career, that Professor Hilgard rejected, about two or three years prior to his death, the data published by him on the humus and humus nitrogen of soils in the California Experiment Station Report for 1892-3-4. It is to be presumed that this implied a rejection of all similar determinations theretofore made. A specific report is here mentioned because it gives analyses for humus and humus nitrogen of soils which were later examined in the same laboratory and shown to contain very much less humus nitrogen than that shown in the report. This was discovered by comparison of data in the report above mentioned with others given by Professor Loughridge in the paper above cited.

Any data therefore which were obtained in a determination of the nitrogen in the ammonia extract of soils are clearly shown above to be entirely unreliable. The reason for the low nitrogen obtained in the humus of humid soils by the same method is puzzling. It may, however, be explained by the following theoretical consideration. Soils from humid regions taken by and large, are admittedly possessed of greater absorbent internal surface, due either to a higher organic matter content, a larger clay content, or to both. For this reason, the humid soil being extracted on the filter would absorb more ammonia from the solution employed for extraction than the arid soil. Hence less ammonia would be absorbed by the colloidal humus solution in the filtrate, and therefore the error in the humus nitrogen, due to absorption of ammonia nitrogen as above proved, would be very much decreased. The opposite would of course be true in "organic matter poor" or "clay poor" arid soil. The great avidity with which soils will absorb ammonia has already been commented on and proved by many investigators, including Hilgard himself. The latter has discussed this subject in his book which is referred to above. This fact would therefore appear to lend further support to the theory above expressed.

On the other hand, the data which were obtained in the method of fixed alkali extraction of the humus and which still show high values for humus nitrogen, cannot be explained by the foregoing considerations. The writer can only say that the method of calculation, absorption of ammonia from the laboratory air, or some other error of that nature, must be responsible for the high nitrogen values obtained. In my knowledge, whether in working with the same soils with which Hilgard's former associates worked, or with others, there has never been an instance of a higher humus nitrogen percentage than 7 or 8 when the KOH or NaOH extraction method for humus was employed.

In view of all these facts and queries, it appears necessary to make a still further critical examination of the method in question, using the same soils as were heretofore employed by this experiment station and of which supplies are still extant. This we shall proceed to do at once, and the writer hopes to be able to report soon not only the results to be obtained, but also a critical discussion of the humus determination itself and its value, together with such review of past work and theories as may be pertinent in that regard. The statement here made is, however, felt to be urgently necessary in explanation of the fact that the pristine position of this division of the California Experiment Station, with respect to humus and humus nitrogen, is one to which we no longer adhere. As successor to Dr. Hilgard in the direction of the work in soil chemistry at the University of California, a position which the writer has the great honor of holding, he feels it incumbent upon him to make this public statement.[1]

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[1] Since the above statement has gone to press and proof received, the author has noted the appearance of a brief paper by F. J. Alway and E. S. Bishop (5) dealing in part with the same subject and in substance agreeing with his statements. Some points of disagreement do exist, however, which will be discussed in our later publication based on more complete experimental data which we hope may soon be ready for the press.

PRELIMINARY EXPERIMENTS ON SOME EFFECTS OF LEACHING ON THE SOIL FLORA.[1]

By C. B. Lipman, *Professor of Soil Chemistry and Bacteriology*, and L. W. Fowler, *Student, University of California.*

Investigations carried out in this laboratory (7) which will soon be reported in detail have demonstrated that marked changes in the physical and chemical condition of alkali soil result from the leaching thereof for the purpose of the removal of the salt. These changes, taken together with the renewed efforts now being made in the direction of reclamation of alkali land by tile draining and flooding, have suggested to the senior author the query as to the effect of such procedure on the soil flora as well as on the chemical and physical constitution of the treated soil. The writers, therefore, decided to carry out first some preliminary experiments on the subject dealing with some of the effects on the soil flora, to a degree which might be indicative of future procedure. The results of these preliminary experiments are so striking as to merit publication prior to the amplification of the work under field conditions.

The soils employed were a blow sand from a peach orchard near Oakley and a clay loam from the University Farm at Davis, Cal. Unleached soils and soils leached in the presence or absence of different salts were all tested for ammonification, nitrification, and nitrogen fixation. The quantities of salts used, in cases in which each salt was added separately to the soil at all, were NaCl .1 per cent, Na_2SO_4 .25 per cent, and Na_2CO_3 .05 per cent. For purposes of a combination of salts we employed the following, NaCl .10 per cent, Na_2CO_3 .05 per cent, and Na_4SO_2 .10 per cent. It will be noted that all of these quantities of alkali may be regarded as relatively small and such as might not interfere at all seriously with many crop plants through direct physiological effects. In carrying out the leaching, quantities of soil with and without salts were placed on filters in large funnels, and all of them, with the exception of the normal soil, which was used as a check, were leached with distilled water in quantities sufficient to remove the salts. The soil therefore which received no salt in all series, but was leached, was treated with just as much distilled water as the salt treated soils. The usual chemical methods were employed in testing for the presence or absence of salts in the leachings. After the leaching was complete, all the soils to be tested were spread out in thin layers to dry in the air of the laboratory. When dry they were ground and sifted for use in the following tests.

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AMMONIFICATION.

Fifty-gram portions of every soil type and condition to be studied were placed in tumblers and mixed in the dry state, with 2 per cent blood in Series I and with 2 per cent cottonseed meal in Series II. Water was then added in the usual way to make an approach as nearly as possible to optimum moisture conditions, the soils were again thoroughly mixed, the tumblers covered with a Petri dish cover, and incubated for 15 days at 25° C. At the end of the incubation period the soil was transferred from the tumblers to copper distilling flasks, magnesia added, and the ammonia present distilled into standard acid, the excess of which was titrated as usual. The results showing the amounts of ammonia produced in every soil are given in Table I. The amounts of ammonia present in the original soil in every case have been subtracted from the amounts found by the analytical procedure just described.

TABLE I.

SHOWING AMOUNTS OF AMMONIA, IN MILLIGRAMS, PRODUCED BY LEACHED AND UNLEACHED SOILS.

SERIES I.—DRIED BLOOD.

Name of Soil	Unleached soil	Leached soil	.1% NaCl plus leaching	.25% Na_2SO_4 plus leaching	.05% Na_2CO_3 plus leaching	All salts as above plus leaching
Oakley	56.00	48.58	54.74	46.34	43.26	45.64
Davis	92.26	89.74	97.30	107.66	83.16	111.30

SERIES II.—COTTONSEED MEAL.

Name of Soil	Unleached soil	Leached soil	.1% NaCl plus leaching	.25% Na_2SO_4 plus leaching	.05% Na_2CO_3 plus leaching	All salts as above plus leaching
Oakley	28.14	30.10	31.78	25.48	25.76	22.26
Davis	21.00	31.64	27.72	34.86	25.48	32.34

The data in Table I, while indicating undoubted effects resulting from some forms of leaching, clearly indicate that such effects are neither profound nor regular. This is particularly true of the Davis soil and the results obtained therewith. Thus leaching in its various forms depresses the ammonifying power of the Oakley soil for blood, but stimulates the ammonia producing power of the Davis soil for cottonseed meal. In all but two cases, in which minor depressions occur, the ammonifying power of the Davis soil is also stimulated so far as blood nitrogen is concerned. Unlike the Davis soil, however, with respect to cottonseed meal, the Oakley soil is in most cases depressed in ammonifying power by leaching, and in the two cases in which it appears to be stimulating, namely, those of leaching without salt, and with NaCl, the stimulation is not great and may not be outside the boundaries of error in ammonification work. The greatest depression in ammonification with the Oakley soils occurs in the case of leaching in the presence of Na_2CO_3 with blood as the ammonifiable material and amounts to about 23 per cent of the total amount of

ammonia produced in the unleached check of normal soil. When cottonseed meal is employed the greatest depression in ammonifying power of the same soil occurs when leaching is carried out in the presence of a mixture of all the salts and amounts to about 21 per cent of the amount of ammonia produced by the unleached check soil.

In general, therefore, a study of the results given in Table I seems to indicate a definite yet relatively small average depression in ammonifying power of the Oakley soil induced by leaching, no matter which of the two forms of organic nitrogen is employed. On the other hand, the Davis soil appears to be stimulated in ammonifying power for both forms of nitrogen through the process of leaching, a depression occurring only twice in the case of the dried blood series. One of these depressions is very slight and the larger one of the two amounts to less than 10 per cent of the amount of ammonia produced by the unleached check Davis soil. The exact causes of the differences between the behavior of the two soils, which has just been noted, can be given only when further researches, on the composition of the leachings from the soil, have been completed. We may perhaps be permitted to surmise that such causes are directly traceable to the difference in the permeabilities to water of the two soils. The Oakley soil being much more permeable to water and containing less actual and "potential" colloidal material than the Davis soil, will allow of a more ready removal of more or less soluble salts, including the important bases set free by exchange of bases in the case of leaching in the presence of salts. This must result in a much more dilute and hence less congenial medium for bacterial development in the Oakley soil. On the other hand, the inferior permeability to water of the Davis soil permits it to retain larger quantities of the bases set free by exchange, and hence stimulation to ammonification may result from the presence of the latter. These are merely mentioned here as tentative suggestions toward the explanation of the results given in Table I. The writers make no claim to the entire adequacy of these suggestions in the premises, nor do they believe they are free from flaws, but pending attainment of further experimental evidence on the subject, they may be of interest to our readers.

NITRIFICATION.

In the nitrification tests 100-gram portions of the soil above described, instead of 50-gram portions, were employed. Dried blood, cottonseed meal, sulfate of ammonia, and the soil's own nitrogen, were employed. They were incorporated with the soil after the manner used in the ammonification experiments, the first and second being used at the rate of 1 per cent of the air dry soil, sulfate of ammonia at the rate of 2 per cent, and the soil nitrogen in the quantity and condition naturally existing in every soil. Owing to the exigencies of laboratory work at the time, the period

of incubation was reduced, contrary to our usual practice in nitrification work, from thirty to twenty-four days. The nitrate determinations were made by the phenoldisulphonic acid method. The very striking results obtained are set forth in Table II, which follows.

TABLE II.

EFFECT OF LEACHING IN THE PRESENCE AND IN THE ABSENCE OF SALTS ON NITRIFYING POWERS OF SOILS. RESULTS IN MILLIGRAMS OF NITRATE PRODUCED.

Forms of Nitrogen Used	Unleached Soil		Leached Soil		.1% NaCl + leaching		.25% Na_2SO_4 + leaching		.05% Na_2CO_3 + leaching		All salts as above + leaching	
	Oakley Soil	Davis Soil	Oakley Soil	Davis Soil	Oakley Soil	Davis Soil	Oakley Soil	Davis Soil	Oakley Soil	Davis Soil	Oakley Soil	Davis Soil
Soil Nitrogen	2.30	3.80	.30	1.40	.20	.28	.30	2.60	.90	.00	.55	.00
Dried Blood Nitrogen	–.10	13.80	.00	.28	.00	.00	.00	.00	.00	.00	.00	.00
C. S. Meal Nitrogen	2.90	11.80	.35	2.20	.00	.00	.00	1.10	.00	.00	.00	.00
$(NH_4)_2SO_4$ Nitrogen	.60	4.80	.00	1.20	.00	.20	.00	1.30	.00	.00	.00	.00

The results given in Table II are as unequivocal an answer to our query with respect to nitrification as we could possibly expect. The harmful effects of leaching on the nitrifying flora of both soil types are clearly manifest both in the presence and absence of salts, but are very much more marked in the former. In a word, we appear to have almost entirely deprived the two soils of their nitrifying power for at least fertilizer nitrogen by means of the leaching. We certainly have done so when salts were present except possibly in the case of Na_2SO_4. The most harmful effect of salts plus leaching is to be noted in the case in which all salts were added to the soil and leached. This is so in spite of the fact that the total salt concentration employed was no greater than in the case in which Na_2SO_4 alone was employed. The salt next in order of damaging effect is probably the Na_2CO_3, and the third the NaCl. Sodium sulfate appears to be definitely much less harmful than the others. It will be further noted that while the two soils are totally different in nitrifying powers in the unleached condition, they are similarly affected by leaching in the presence of salts. It appears also that the form of nitrogen which is least affected by the prior leaching is the soil's own nitrogen, despite the fact that it was the only one which was subjected to the leaching process. Finally, it is of great interest to note that, while the salts were all removed from the soil before the latter was used, the actual removal of the salt has, in the case of every one, left behind a characteristic effect. Thus, as between the three single salts the order of harmfulness beginning with the most harmful should probably be Na_2CO_3, NaCl, Na_2SO_4. It is therefore not unlikely that we find herein further support for the theory advanced elsewhere by the senior author (5), that one of the most

serious phases of alkali injury is due to the effect of the salt on the soil rather than on the plant which is only indirectly affected. This seems to be supported by the order of injury induced by leaching out the different salts which is above referred to.

Not only are the nitrification data of striking interest and significance when considered alone, but also when compared with the ammonification data above discussed. Whereas ammonification is doubtfully, or at least not profoundly affected by the leaching process as carried out by us, nitrification is not only profoundly affected and largely inhibited, but it is brought to an absolute standstill in some cases and almost so in others. The senior author desires therefore again to call the reader's attention to his discussion (2) with reference to the great disparity in the physiological requirements of the two processes in soils, since space in this paper will not permit of further discussion of that subject. Numerous points other than those above mentioned are brought to our attention by the data in Table II, but we must refrain in this preliminary communication on the subject from giving them expression. They will receive full attention in future papers.

Non-Symbiotic Nitrogen Fixation.

Like the ammonification and nitrification tests above described, the nitrogen fixation tests were carried out in soil cultures. To 50 gm. of soil 1 gm. of mannite was added and thoroughly mixed therewith. The necessary water was added and the mixture again thoroughly stirred. The tumblers were then covered with Petri dish covers and incubated for three weeks under the same temperature conditions as the cultures in the other series. At the end of the incubation period, the cultures were dried at 100° C., ground and analyzed for nitrogen by the method (3) in use in this laboratory. The results showing the amounts of nitrogen fixed are given in Table III, which follows.

TABLE III.

SHOWING THE AMOUNTS OF NITROGEN FIXED, IN MILLIGRAMS, PER GRAM MANNITE USED IN THE VARIOUS CULTURES.

Name of Soil	Unleached soil	Leached soil	.1% NaCl plus leaching	.25% Na_2SO_4 plus leaching	.05% Na_2CO_3 plus leaching	All salts as above plus leaching
Oakley	11.20	11.20	7.70	7.00	8.40	7.00
Davis	19.25	14.35	7.00	11.90	1.40	3.15

It is very clear from the foregoing data that the effect of leaching is quite manifest on the nitrogen fixing powers of the soils tested. In the case of the Oakley soil leaching has markedly decreased the nitrogen fixing power, but only in the soils from which added salts had been

leached. In the case of the Davis soil, even leaching without previous salt addition induced a marked inhibition to nitrogen fixation. While the depression as stated was marked in both soils, it was, however, much more marked in the Davis than in the Oakley soil. In other words, leaching affected nitrogen fixation in both soils much as it did nitrification and not in the manner of its action on ammonification. To be sure, the injury is not, speaking in the absolute, anywhere as great to the soil's nitrogen fixing power as it is in the case of its nitrifying power.

From the theoretical standpoint one would be led to expect that both nitrification and nitrogen fixation would be similarly affected in the Davis soil and more profoundly so than in the Oakley soil. This is for the reason that the plentiful supply of colloids which are contained in the Davis soil would be diffused by leaching, and through their diffusion would seriously limit the air supply which is so essential to the two processes in question. No doubt, however, other effects induced by leaching operate toward the same end as the limitation of the air supply, but we shall defer discussion of them until more data have been gathered. It is interesting to note here, however, that Na_2CO_3 alone, or with the other salts, appears to be the most injurious salt in the case of both nitrification and nitrogen fixation, even though only the residual effects of its erstwhile presence in the soil remain. This is particularly noteworthy here because it is in accord with findings (1, 4) by the senior author on the effect on the nitrifying and nitrogen fixing bacteria of Na_2CO_3 as compared with the other salts when the latter are allowed to remain in the soil.

Concluding Remarks.

In addition to the studies on the effects of leaching on the ammonifying, nitrifying, and nitrogen fixing soil flora which are above reported, the senior author carried out an additional test with regard to the cellulose destroying bacteria. This consisted in placing in different Petri dishes in accordance with a method described in this journal (6), some unleached Davis soil, some leached Davis soil, and some leached Davis soil which had received prior to leaching .2 per cent KCl. These soils were properly moistened and discs of filter paper placed in contact with their surfaces. After two weeks' and even after four weeks incubation the leached soils showed no disposition to attack the filter paper. In the case of the unleached soil, however, after only two weeks most of the filter paper had disappeared.

In general, therefore, while it is still too early to draw any hard and fast conclusions from the experiments above briefly discussed, it seems quite certain that leaching affects the bacterial flora of soils profoundly. From the evidence adduced from our experiments, this is particularly so for the nitrifying, nitrogen fixing and cellulose destroying organisms. All of these processes appear to be wholly or almost wholly checked by

leaching, especially if salts are present prior to the execution of the latter process. It now remains to be seen if leached and underdrained alkali soils are injured as were the soils above studied, and if the injury done is or is not merely an ephemeral one which may entirely disappear in a few months under field conditions. The authors are now proceeding to a study of these questions in alkali soils in the field. Also they are inaugurating experiments on the effects of leaching alone, in the absence of salts, which should, in view of the results reported above, also yield highly interesting results. The latter will be particularly important from the practical standpoint because of their cogency in connection with all irrigation operations, and particularly with that of the practice of irrigation by flooding. Much damage has already been noted on relatively new soils where the last named system has been in vogue, and it is hoped that the experiments may lead to the discovery of the cause or causes of such damage.

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